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PHOTONUCLEAR STUDIES IN THE FEW NUCLEON SYSTEM

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PHOTONUCLEAR STUDIES IN THE FEW NUCLEON SYSTEM*

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A few years ago there was a conference at Asilomar¹ which was on photonuclear physics and was the high water mark (or perhaps the swan song) of that particular field. I had the amusement of summarizing the properties of the new nucleon system subsequent to that conference² and what I would like to do is use this occasion to update that report, to comment on some of the problems that have been solved subsequent to that meeting (which was approximately two years ago) and on some of the problems which have come up since that time.

I think the most significant problem at that time was in the photodisintegration of the deuteron and it is very nice to report that a very beautiful experiment³ has been done at Mainz which resolved a vexing discrepancy. This experiment, which I will talk about prior to discussing the historical difficulty, essentially consists of a measurement of the total photon absorption of the deuteron in a limited but vital energy region. Figure 1 shows the basic data points. In this experiment, unlike all the other ones where you sit there and

* This work was performed under the auspices of the United States Energy Research and Development Administration.

detect a neutron or proton emitted from the photodisintegration, they took a long, I don't know how long, tube of water and shot photons through it and detected the number of photons at the other end. Then they took a long tube full of heavy water and they took a great deal of care to make sure they had the same amount of material as the previous one and shot photons through it and then they took the difference in the number of counts they got between them. Then they made a very, very small correction, which I will discuss in a minute, for the fact that the pair production cross section is different. Now, the trouble with this kind of experiment is that the atomic absorption is a 100 or 1,000 times, I don't remember precisely, the nuclear absorption so you have to do the experiment with great care. You have to make the subtraction very carefully. The beauty of it is the independence of how you detect charged particles or neutral particles and it is also independent of how you monitor the beam. This seems to be the thing that has fouled up other experiments which I will discuss and which were the source of controversy at the time of Asilomar.

Anyway here in Fig. 2 is the result of the Mainz experiment: the data points of the previous Fig. 1 essentially have been condensed into these three; the solid curve thru them is typical of potential theory calculations for the photodisintegration and basically consists of starting with a static potential which fits the nucleon-nucleon scattering data and then calculating the continuum and the deuteron ground state properties: then inserting the static nonrelativistic multipole operators (thru the electric

octopole and magnetic dipole). This is a calculation done by Partovi⁴ approximately 10 years ago. There have been a number of calculations of a similar nature since then which confirm it.⁵ As you can see the calculation fits the experiment beautifully in this region and it is precisely the region where one expects the theory to work so isn't that just delightful.

Now the reason that this is such a major piece of progress is that two years ago one had a very carefully done experiment which produced the lower set of points in Fig. 2. These are from a very careful experiment done by John Baglin⁶ and collaborators at Los Alamos. No one has yet been able to fault that experiment but the results are 20% smaller than the theoretical curve in precisely the region where one expects nonrelativistic quantum mechanics and classical electromagnetic theory to work. That was an extremely disturbing result which it would appear one can stop worrying about. It would however be very nice if sometime, some place, someone else measured some of these things so that one would have an independent check.

The only other modern experiment that I am aware of which talks to this point is some recently published work from the Saskatoon Laboratory⁷ which did an electro-disintegration of the deuteron, Fig. 3. They did it in a very special way. They looked only at electrons which were very gently scattered, that is had very small momentum transfers, in which case you can apply what is called virtual photon theory. Then you can relate in a very simple way the electro-disintegration cross section to the photo-disintegration cross section. That process is subject to uncertainties that involve taking

differences of cross sections, it involves certain theoretical assumptions which have never been justified and it is also applied in an energy region where it may not work. It seems to work if the energy loss is less than 10 MeV. In any case the hatched region is the old Baglin⁶ experiment which was on the previous slide. The little dots are the results of the Saskatoon (e,e') experiment, the curve is Partovi's⁴; the Mainz results, with somewhat smaller uncertainties, also fit Partovi's⁴ result and one sees consistency between the Mainz and Saskatoon experiments and potential theory.

It would be presumptuous to suggest that because the Mainz point at 25 MeV is slightly below theory (although well within statistical uncertainties) that perhaps something interesting, albeit small, is taking place, but in the absence of precisely measured points at higher energy one cannot be sure.

One of the beauties of the Mainz experiment is that it can measure the total cross section very accurately, very independent of correction. The Mainz experiment is a 5% absolute cross section. The theoretical correction they must make in it, having to do with the difference in pair production between H_2O and D_2O , is 1% so the uncertainty in that is unimportant. But it can only do total cross sections and that supplies us with only a very limited amount of information. Again from Saskatoon there is the cross section at 20 MeV as a function of angle, Fig. 4; this is again using electro-disintegration data which is then switched over to photo-disintegration data. The fact that it begins to fail at the large angles probably is not significant; that is where you would begin to believe that at the

larger momentum transfers the more inaccurate that process of switching from electro- to photo-disintegration data would become. Nevertheless it would be nice if someone would do this with real photons and perhaps with uncertainties the same size because as we will see in a minute there are other effects contributing in this region. They are hopefully very small and would not effect things like a total cross section at all and the angular distributions hardly at all but nevertheless they may show up if one has a sufficiently accurate experiment. And again the contribution from Saskatoon is a 90° cross section, Fig. 5, as a function of energy in this low energy region where the E-1 multipole dominates. If everything can be believed here that means that the deuteron in the low energy region is a finished thing. You know it as a monument and you can put it away, and one can go on to more interesting things.

The only difficulty is that there is another thing that you can measure besides total cross-section and angular distributions and unfortunately people have measured it. It is the polarization; for the neutron at 90° as a function of gamma ray energy, Fig. 5. Now this is the old Yale experiment and the data was taken in 1969 and results were published in 1972.⁸ The hatched region is a standard deviation around these experiments. They are very difficult experiments.

This line, of course, is Partovi's⁴ calculation using only the electric dipole, quadrupole, octopole, magnetic monopole. He has not included exchange currents or isobars which have recently been shown to contribute to the polarization even in this "classical" region. Anyway you can see that if you believe in the experiment and you believe in the calculation there is a clear discrepancy at 90° , Fig. 6. The

measurement was also performed at 45° , Fig. 7, and that also deviates from the experiment. One important point to note, which we will return to, is that the polarization at 45° was initially negative and became positive, in this experiment, at around 20 MeV and then seems to continue positive.

There have been a number of calculations which show that the deuteron is not quite the static thing that can be adequately described by nonrelativistic quantum mechanics. One of the most exciting things at Asilomar was the calculation of Brown and Riska⁹ indicating that the famous discrepancy of 10% of the thermal capture cross section was removed by the inclusion of explicit meson exchange currents. Now these do not contribute appreciably to the total cross section once one gets away from threshold. They do not have a measurable effect on the angular distribution. But the polarization is predominately due to an interference effect between electric dipole and the magnetic spin flip amplitudes¹⁰ and these exchange currents do appreciably alter the magnetic spin flip matrix element.

Now there are two calculations including this effect. One is by Hadjimichael,¹¹ Fig. 8, who is in the audience and can defend himself; he has calculated at two angles, 90° and 60° . I do not recall which potential he employed for the conventional part of the calculation. It's not important because the deuteron, in this energy region, is extremely insensitive to this point as has been demonstrated by Gregory Breit¹ and his many collaborators. The potential calculation is represented by the solid line. The dashed line is the new polarization when pion exchange currents are included with perturbation theory. The point to

recognize, and I'll come back to it in a minute, is that this changes the polarization by approximately one experimental standard deviation on the basis of the old Yale experiment. The reasons for bringing this up is that if you talk to the people at Yale about their experiment they will give away a standard deviation without any pain whatsoever, because of multiple scattering corrections in the target and uncertainties in the analyzer. But the point really is that this calculation, and the calculation of the Mainz group that I will report on in a moment, change the polarization by another standard deviation so it is quite possible that actually there may exist a discrepancy between the old Yale experiments and these new calculations.

Now the other calculation is that of Arenhoval,¹² Fig 9, who is also here to defend himself, and this has been extended over a much larger energy region and it differs from Hadjimichael's calculation predominantly in the fact that the Mainz group has included the effect of nuclear isobars. This has a very small effect in the region that Hadjimichael was calculating but does effect things as you go to higher energy. Now there are two points: one, this calculation never gets to a positive polarization, whereas the old Yale experiments did indicate that the polarization become positive although at a slightly different energy. It would be nice if the sign of the polarization could be determined at 75 MeV just to see whether it is positive or negative, but unfortunately even this is not a gross quantity.

At Yale they are doing a new experiment, which I can't judge, but according to Dr. Firk,¹³ it should solve all these problems. Instead of using a

mixture of deuterium and some other junk which requires subtraction, they are using a liquid deuterium target and they are being very careful doing multiple scattering corrections in the target and all the sort of stuff. The analyzer is much more precisely known. So hopefully in the next 6 or 7 months we should have an idea of what this is all about. They are the only people, that I know of, doing this experiment.

If people accept the idea that the deuteron is an important building block in one's knowledge of nuclear physics, it would of course be nice if someone else were to measure these things, because one experiment seems to be a brilliant provocation but it often doesn't tell you anything. It frequently just creates a lot of dissension and confusion.

The last viewgraph on the deuteron, Fig. 10, before we lay it to rest, is the calculation of the total cross section from the Mainz group.¹² The point there is to show that the effect of the isobars and the effect of the exchange currents become more important at higher energies. One would think these could be observed experimentally and it would be very nice if someone were to do so.

Now to talk about the three body system. The most astonishing thing that I found about the three body system is that there is a huge review article¹⁴ on the experimental properties of that system in a Russian journal which hardly anybody in the United States knows about. I am just going to very quickly whip thru the pertinent figures from that article, which is by Gorbunov, as it is very inaccessible in California and perhaps much of

of the rest of the world. It is a review of their cloud chamber experiments on the photodisintegration of the three body system and I think that people should be aware of it. It is very complete, it differs appreciably from the results of a number of Western experiments and it is impossible for a theorist to know who's right. It makes an enormous difference whose experiments are correct because one is now getting to the point where 20% effects are no longer negligible. It used to be good enough that the curve went up and came down and you could somehow fit it vaguely, and that was a nice thing, but today things are more quantitative.

Figure 11 is the total cross for photon absorption on He^3 from threshold to 120 MeV; Fig. 12 the same in tabular form from which one can extract angular distributions according to

$$\frac{d\sigma}{d\Omega} = A[\sin^2\theta + B \sin^2\theta \cos\theta + C \sin^2\theta \cos^2\theta + \epsilon] \quad .$$

Figures 13 and 14 are the angular distributions themselves, Fig. 15 the three body total cross section, Fig. 17 the neutron's angular distribution, and there is much more information in the article such as proton angular distribution, energy of emitted proton, etc.

Returning to articles linguistically more accessible to me, Fig. 17 is a comprehensive summary of the two body total cross section data available at the end of 1973, taken from a report of an experiment done at Glasgow, and they have a representative here also to defend themselves. The tiny dots are the Glasgow experiment and the higher lying ones with the large error

bars, are Gorbunov's cloud chamber results. There is a clear discrepancy. If we look at a composite of the Western experiments on the two body photodisintegration of helium in Fig. 18 we have this collection of points and we have two curves going thru it. Curve I is a new calculation by Gibson and Lehman¹⁶ and curve II is an older calculation by Barbour and Phillips.¹⁷

These calculations differ predominately in the way they handle the ground state. The continuum states are calculated essentially the same way using separable representations of the two body interactions which fit the low energy nucleon-nucleon scattering data. They solve the equations in different ways but that's not the issue. Presumably they both solve it with great numerical accuracy so that's not the difficulty.

The difficulty is that Barbour and Phillips used an analytic function, an analytic form for the ground state which was fitted to the ground state data and Gibson and Lehman actually used the same nucleon-nucleon potential used for the scattering to solve for the ground state wave functions and proceeded on from there. There is another difference, Barbour and Phillips included the S' state and Gibson and Lehman didn't, which accounts in part for the higher cross section in the Barbour and Phillips' calculation but presumably for only part of it. Now clearly if the Western experiments are correct, that is to say that the Russian experiments are 10 - 15% too high, then one has a good quantitative understanding of the results of the Fadeev equations for the two body photodisintegration of ^3He , and that is just delightful. There are a few small corrections in the order of

10% or a little less which can be added to the Lehman and Gibson calculation, and I suspect they will eventually be included. I think the predominant one is the inclusion of the S' state. They have not done a study of the sensitivity of these results to varying the parameters in the two nucleon interactions. Of course there are uncertainties in what these parameters are on energy shell and, of course, off it and varying them is a tedious thing to do.

Getting onto the three body photodisintegration of ^3He let me show you, in Fig. 19, some data from Livermore which has just been published.¹⁸ There are those who would say there are significant wiggles and others who would not agree. Clearly spectators should be discrete.

Figure 20 has a composite of a variety of experiments. The histograms are the Russian results, the little dots are a conglomerate of data from Glasgow, Livermore and Saskatoon. The two curves were both calculated by Gibson and Lehman,¹⁹ one from their model, and the dotted one is from Barbour and Phillips' model from which they have removed the S' state. These two calculations use the same potentials and can be compared; the difference is entirely in the ground state wave function. Gibson and Lehman, using the solution to the Faddeev equations, Barbour and Phillips their analytic representation. If one accepts this the calculation is slightly too high but nevertheless seems to quantitatively agree with the experiment. The parameter differences in theory are larger than the uncertainties of the "Western data" but not than the discrepancy between the "Russian" cloud chamber results and the "Western data".

If you eat lunch with experimenters in the West they seem to imply that the cloud chamber results are too high, but I have no competence to decide. In any case it would be nice to know what is going on. Here is the last slide on this subject, Fig. 21. These are Gorbunov's total cross section integrated as a function of energy and the bremsstrahlung weighted cross section. The total cross section gives you a value something like 70 MeV -mb, the Thomas-Reike-Kuhn sum rule something like 40 MeV -mb, which means this nucleus is behaving like all other nuclei, namely, an enhancement of a factor like .6 or .8. For the bremsstrahlung weighted sum cross section the only thing that you can say is that if you accept his values you have a result that is compatible with the bremsstrahlung weighted sum rule and the electron scattering size is too high. If you knock his cross section down by 10 or 20 per cent it is then well within the size ball park and one hasn't learned anything startling.

Experiments on the triton would be particularly interesting if one could hope to see some effects due to charge asymmetry other than those expected from explained coulomb energy. The anomalous energy is 100 keV, which implies a 1% effect on the wave functions, hence an observable change of 2%. If one could measure something to that accuracy, this might be very interesting.

Figure 22 shows a recent two body electro breakup of ^3He done at Saskatoon.²⁰ These curves are Born approximate calculations, using different ground states. They have taken the (e,e') experiments and converted them to gamma ray equivalent data and they have plotted the 90° cross section as

a function of energy. Gibson, Lehman and O'Connell²¹ are doing calculations on the electrodisintegration of the three body system and eventually they should be compared directly. There is an interesting experiment which is now still in progress at NBS in collaboration with the University of Massachusetts,²² Fig. 23. This is typical data on (e,e') ^3He for the total cross section. They do a whole lot of energies and angles. The abscissa is the energy lost by the electron. I show this only because it is nice clean data in which the cross section curve goes up and down.

The interpretation one can make of this is the following: if they take the two body photodisintegration and convert that to electrodisintegration they get curve I, Fig. 24. If you add to that the contribution due to magnetic dipole cross section you get curve II. Then if you take the three body photodisintegration data cross section calculated by Gibson and Lehman and then convert that to electrodisintegration and add that to curve II you get curve III. This tells you that things look real nice in the region where you expect E1 cross section to dominate and something funny is taking place at lower energy. The extra cross section has been interpreted as a monopole cross section shown in Fig. 25, where the "extra" cross section has been fitted with the parameters shown. O'Connell at the Bureau of Standards has taken ordinary effective range theory, calculated the E0 cross section and comes up with something very, very similar to this.²³ This would indicate that one has not seen an E0 resonance, only an E0 continuum (potential theory) cross section., which is interesting but not exotic.

Figure 26 is from the same experiment and is chosen to emphasize the discrepancy between the data and curve III. The point is that there is a great deal of cross section left over, presumably E2 and there are lots of ways to have fun with that.

At Asilomar the great controversy in the ${}^4\text{He}$ area was whether or not there were too many neutrons relative to protons. This controversy has now disappeared. Everybody agrees that in the giant resonance region one observes the same number of neutrons as protons. There is one calculation which was subsequent to that time by Londegren and Shakin,²⁴ which is a coupled channel calculation treating the neutrons and protons in separate channels. It gave the same number of neutrons and protons.

There are some new experiments which have come from Toronto²⁵ and I will just very quickly show you the quality of the data, Figs. 27 and 28. These are angular distributions for the neutron as a function of energy for protons on ${}^4\text{He}$. There are to my knowledge no other experiments as detailed. They have taken an enormous amount of data with great care and I believe it will be published soon in the Canadian Journal of Physics. They have extracted from these all sorts of angular distribution coefficients and asymmetry coefficients and stuff like that, Fig. 29. These will be more meaningful when someone has attempted theoretical calculations of their results.

The last thing that I will talk about will take just a minute and it is something that was touched on this morning. That is the data taken at high energies on the photodisintegration of ${}^3\text{He}$ at Saclay.²⁶ Figure 30 is the two body photodisintegration of ${}^3\text{He}$ at two different angles and I think

it is interesting to compare this with a whole pack of previous experiments in Fig. 31. It is clearly important to discover if something is or is not taking place at 400 MeV. Figures 32 and 33 are the same thing for ^4He .

I would like to thank the several experimenters who have allowed their unpublished work to be shown and to acknowledge numerous discussions with many people, particularly the patience of Ben Gibson and Jim O'Connell.

Thank you.

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FIGURE CAPTIONS

- Fig. 1 Photon absorption cross section of deuteron. Experimental data from Ref. 3, curve from Ref. 4.
- Fig. 2 Photon absorption cross section of deuteron. Squares are averaged data from Ref. 1, circles are data from Ref. 6, curve from Ref. 4.
- Fig. 3 Photon absorption cross section of deuteron, circles from Ref. 7, hatched region Ref. 6, curve from Ref. 4.
- Fig. 4 Angular distribution of neutrons from photodisintegration of deuteron Ref. 7.
- Fig. 5 Neutron cross section at 90° from photodisintegration of deuteron, Ref. 7.
- Fig. 6 Neutron polarization at 90° from photodisintegration of deuteron, Ref. 8.
- Fig. 7 Neutron polarization at 45° from photodisintegration of deuteron, Ref. 8.
- Fig. 8 Calculated neutron polarization from Ref. 11. Solid curve is potential theory, dotted curve includes meson exchange current corrections.
- Fig. 9 Calculated neutron polarization from Ref. 12. Solid curve is potential theory, dotted curve includes meson exchange current corrections.
- Fig. 10 Cross section from photodisintegration of deuteron from Ref. 12.

- Fig. 11 Total photon absorption cross section for ^3He from Ref. 14.
- Fig. 12 Angular distribution coefficient from Ref. 14, see text.
- Fig. 13 Angular distribution of protons from photodisintegration of ^3He , Ref. 14.
- Fig. 14 Angular distribution of protons from photodisintegration of ^3He , Ref. 14.
- Fig. 15 Three body photodisintegration cross section of ^3He , Ref. 14.
- Fig. 16 Angular distribution cross section of neutrons from Ref. 14.
- Fig. 17 Total photon absorption cross section of ^3He , Ref. 15 (see text).
- Fig. 18 Calculated and experimental cross section for two body breakup of ^3He , Ref. 16.
- Fig. 19 Three body breakup of ^3He , Ref. 18
- Fig. 20 Calculated and experimental three body breakup cross section for ^3He , Ref. 19.
- Fig. 21 Total and bremsstrahlung weighted cross section for ^3He , Ref. 14.
- Fig. 22 Two body breakup of ^3He , Ref. 20.
- Fig. 23 Cross section for electrons scattered from ^3He , Ref. 22.
- Fig. 24 Cross section for electrons scattered from ^3He , Ref. 22 (see text).
- Fig. 25 Electric monopole form factor for ^3He , Ref. 22 (see text).
- Fig. 26 Electric monopole form factor for ^3He , Ref. 22 (see text).

- Fig. 27 Angular distribution of neutrons from photodisintegration of ${}^4\text{He}$, Ref. 25.
- Fig. 28 Angular distribution of neutrons from photodisintegration of ${}^4\text{He}$, Ref. 25.
- Fig. 29 Angular distribution coefficients as in Fig. 27.
- Fig. 30 Cross section for two body photodisintegration of ${}^3\text{He}$, in region of (3,3) resonance, Ref. 26.
- Fig. 31 As in Fig. 30, compared to other experiments.
- Fig. 32 As in Fig. 30, for ${}^4\text{He}$, Ref. 26.
- Fig. 33 As in Fig. 32, compared to other experiments.

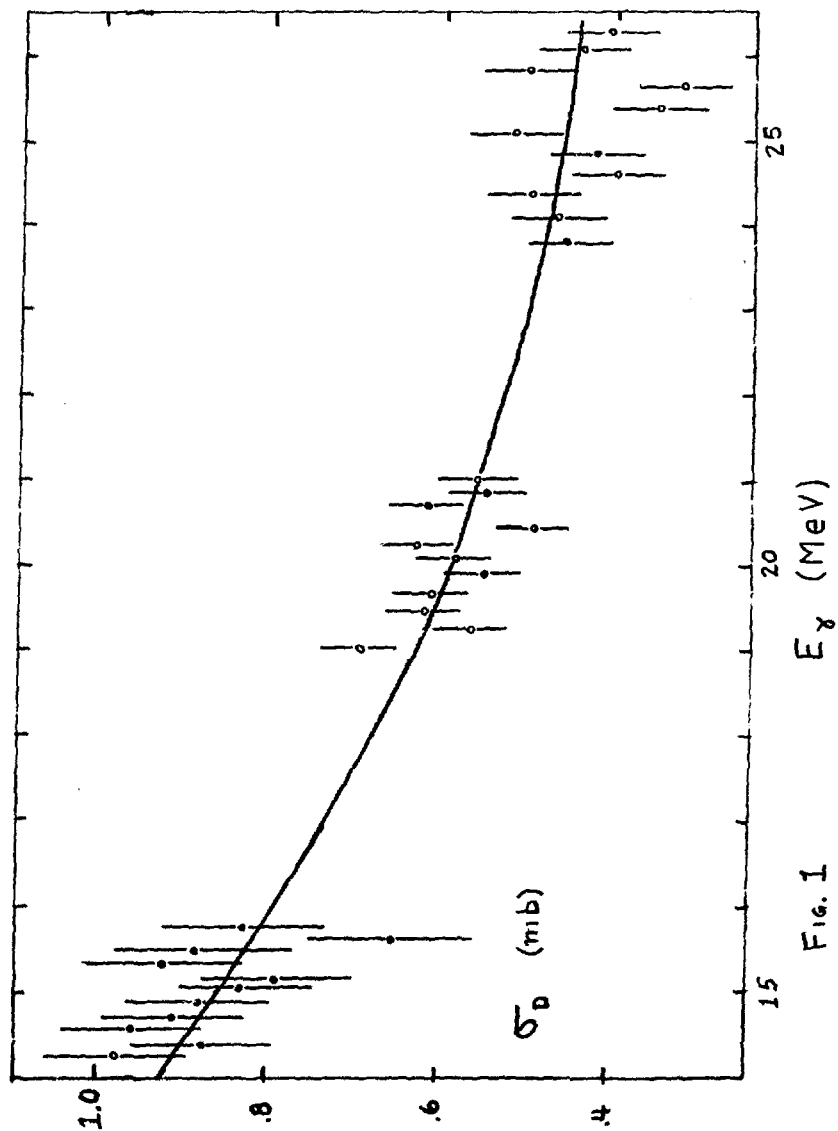
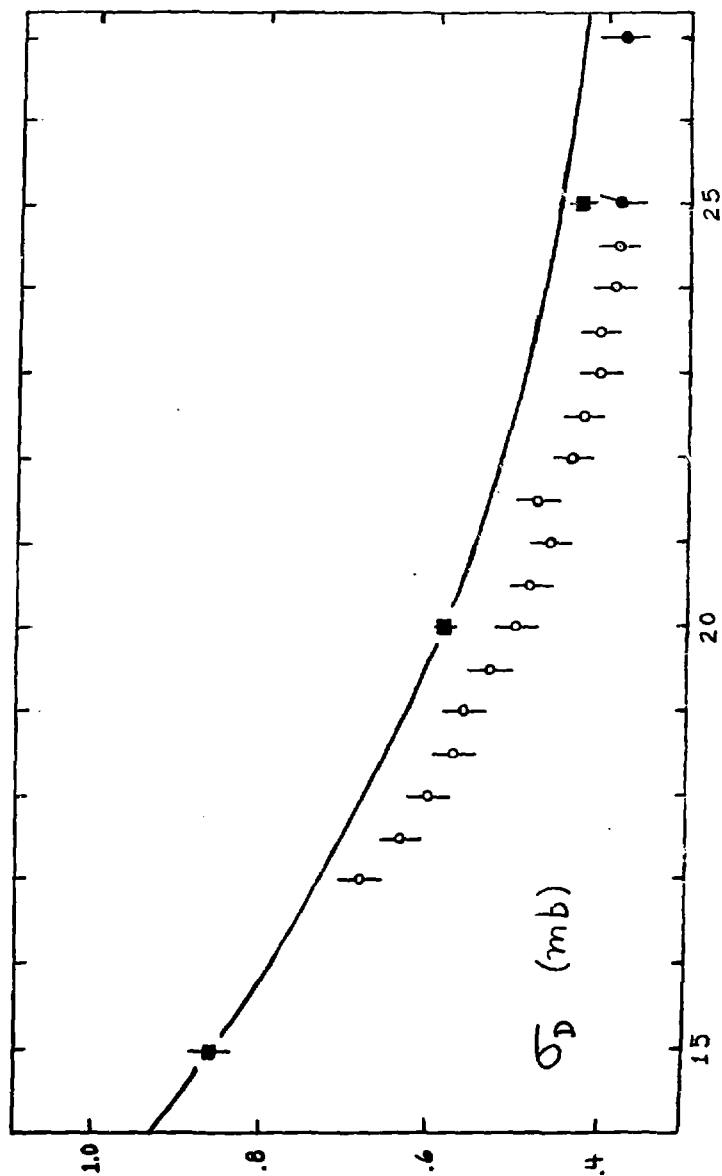


FIG. 1

FIG. 2 E_γ (MeV)

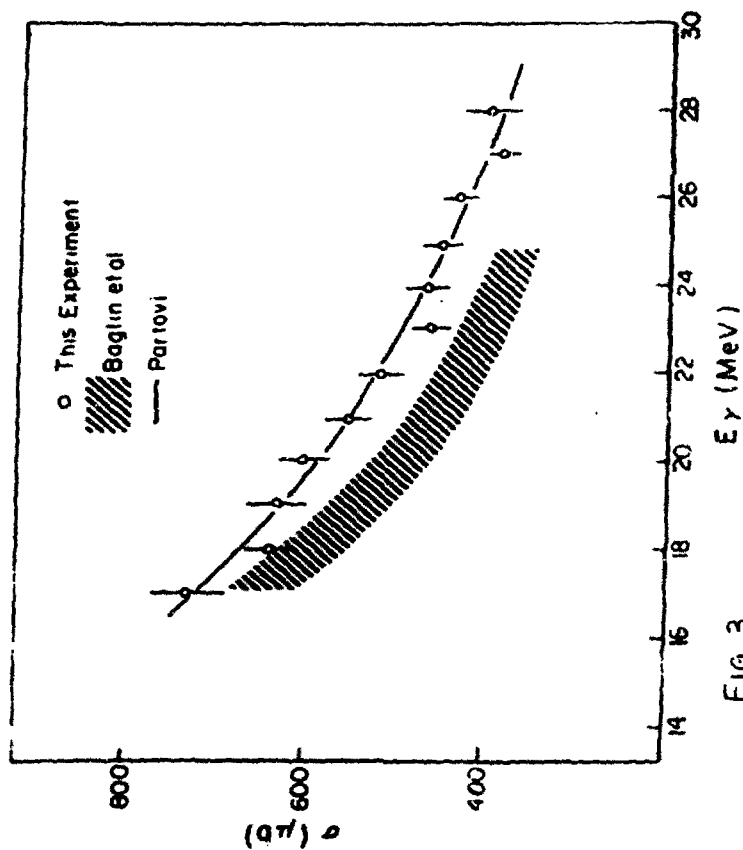


FIG. 3

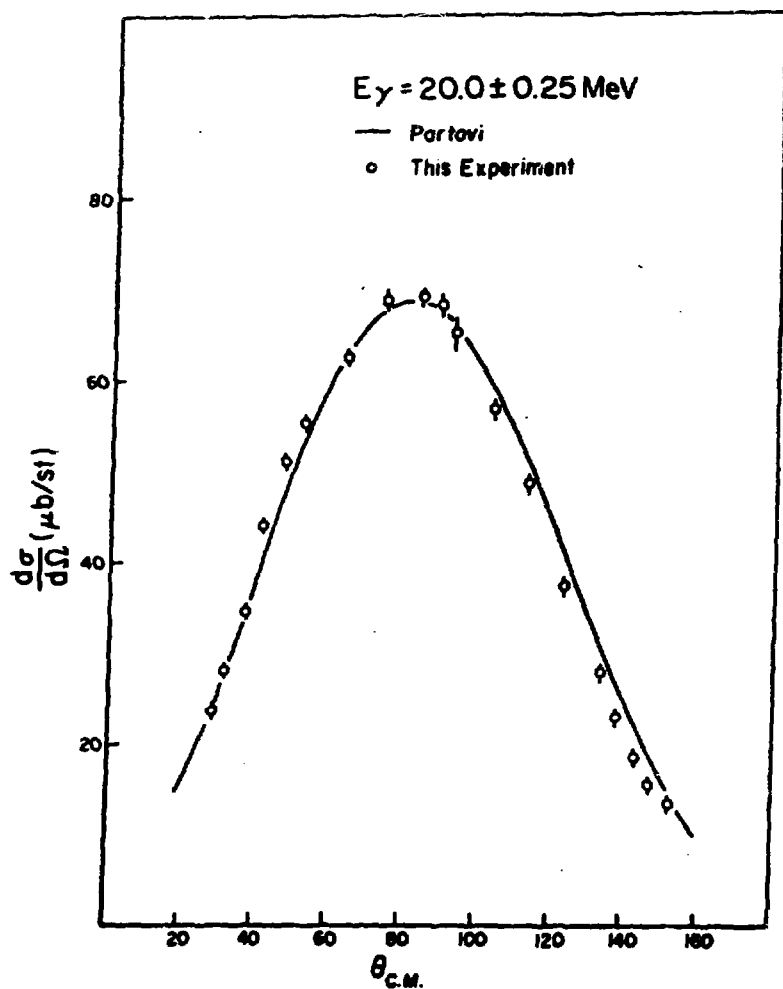


FIG. 4

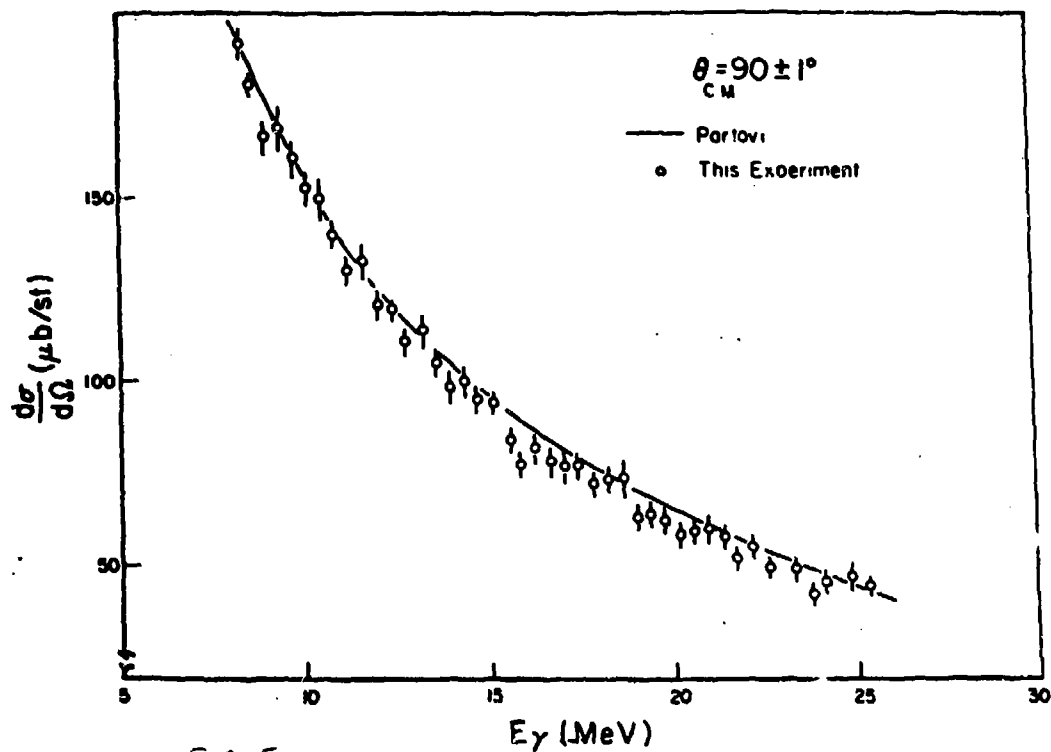


FIG. 5

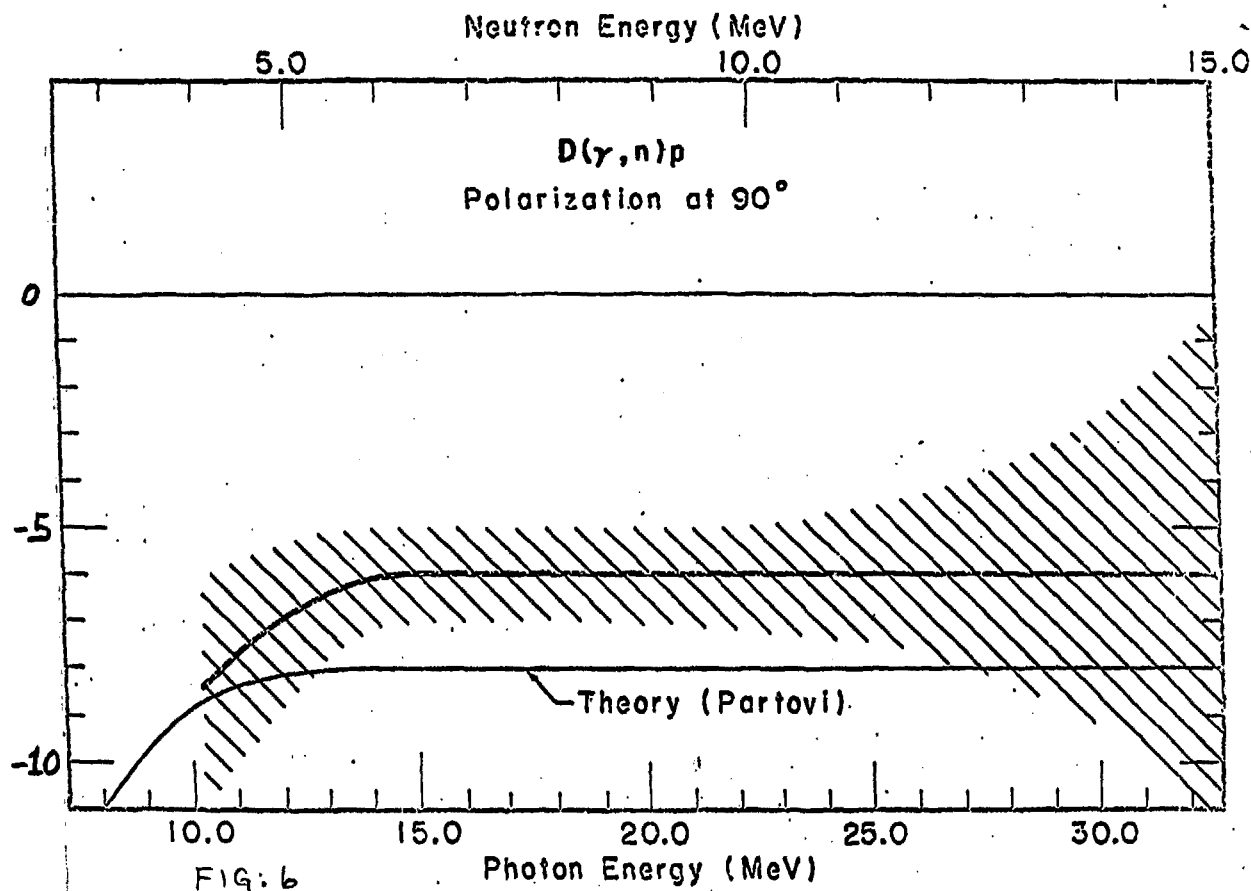


FIG: 6

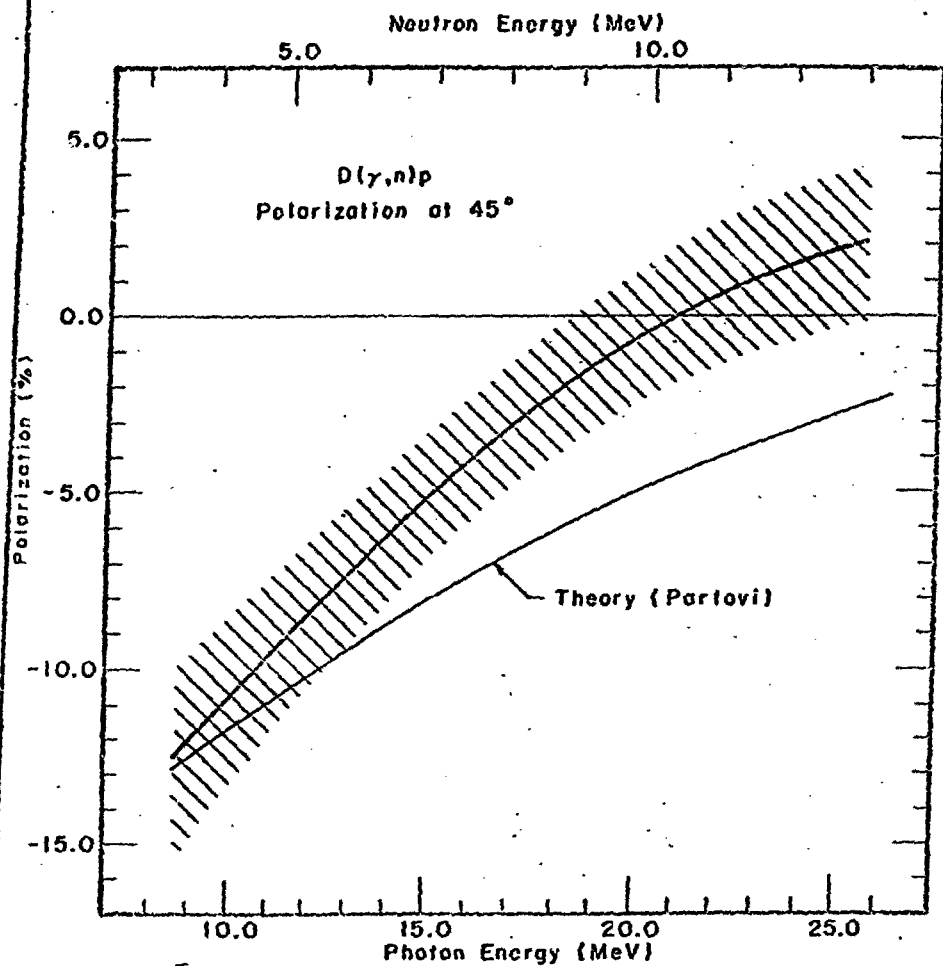


FIG. 7

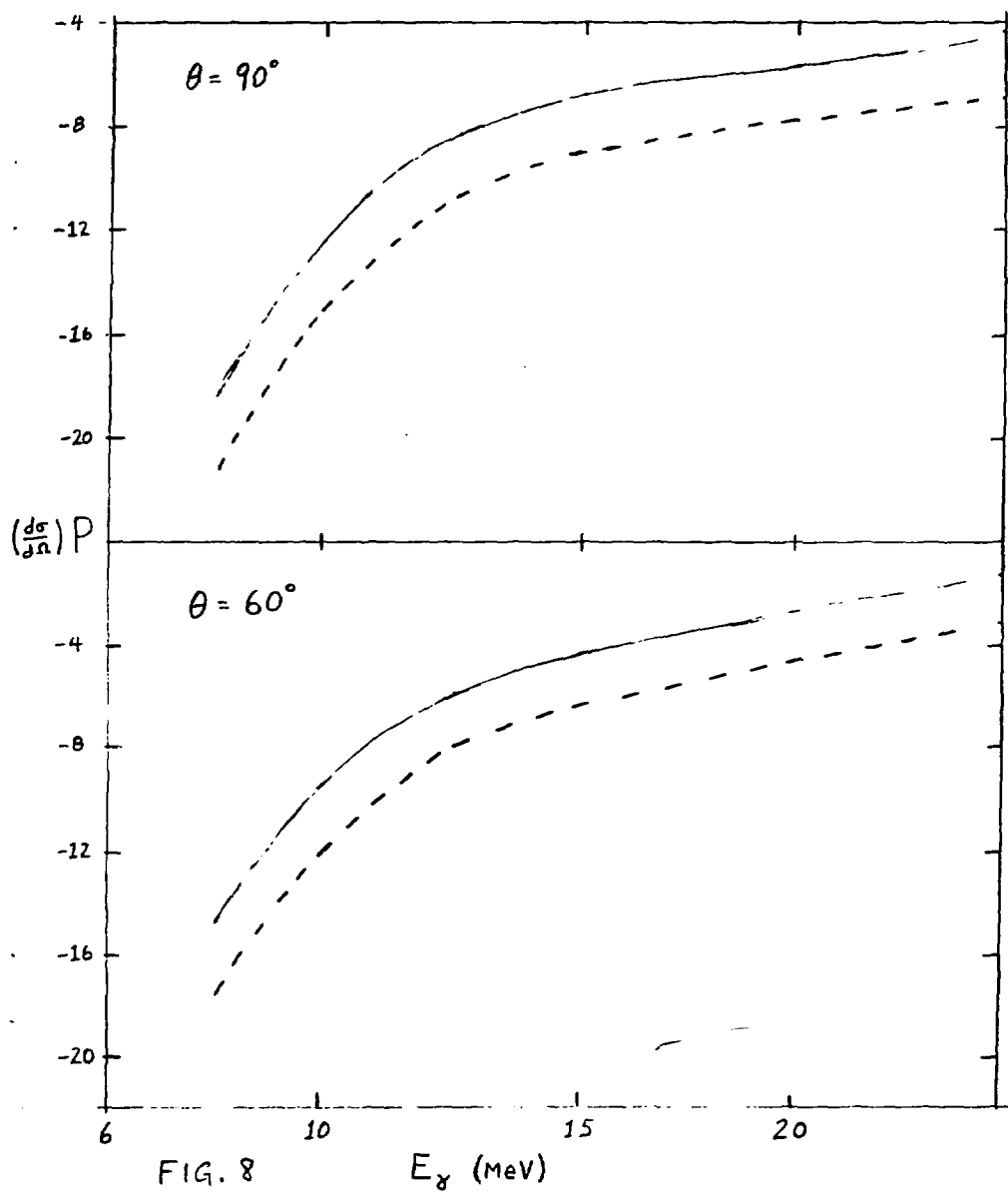


FIG. 8

E_γ (MeV)

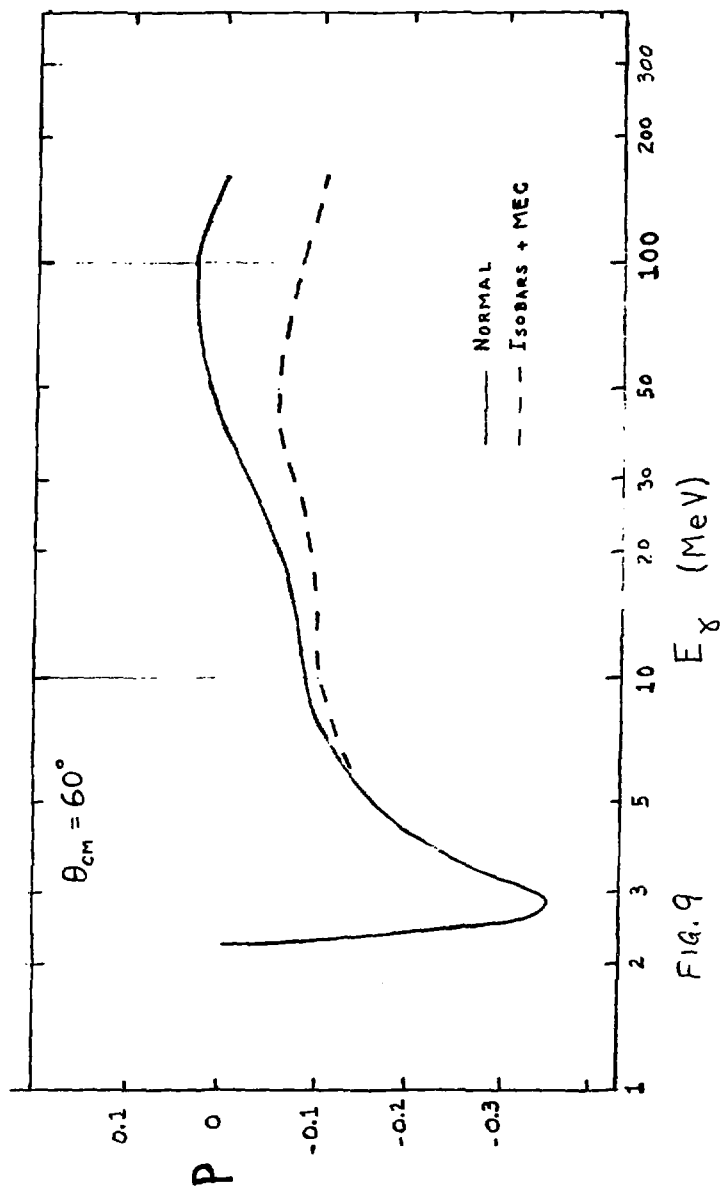


FIG. 9

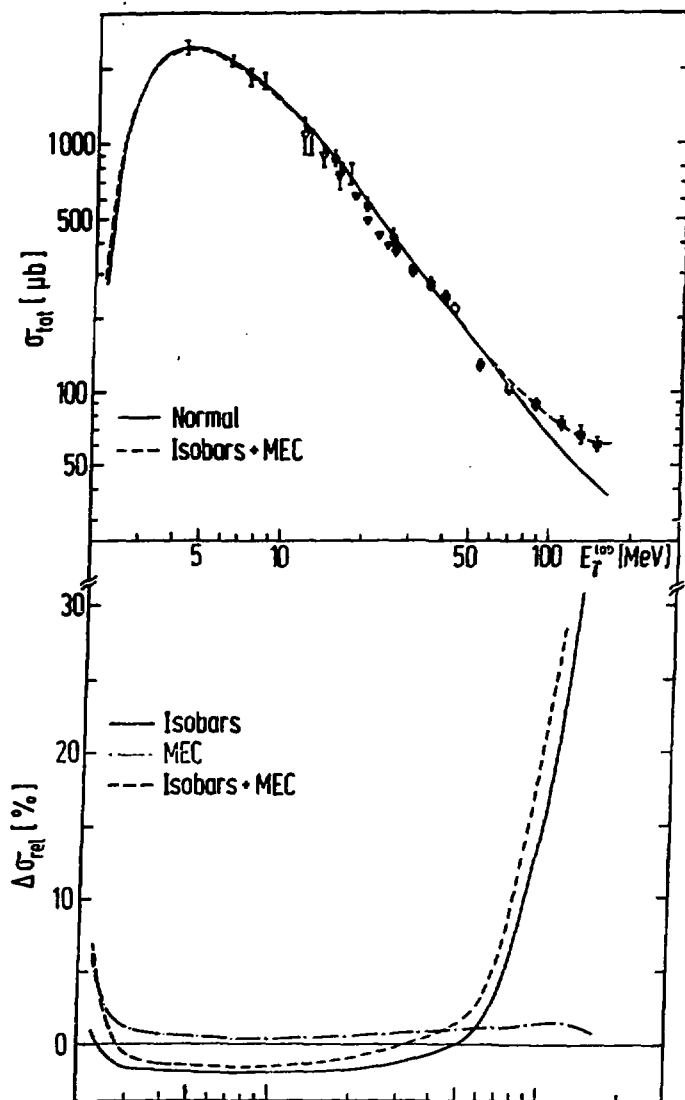


FIG. 10

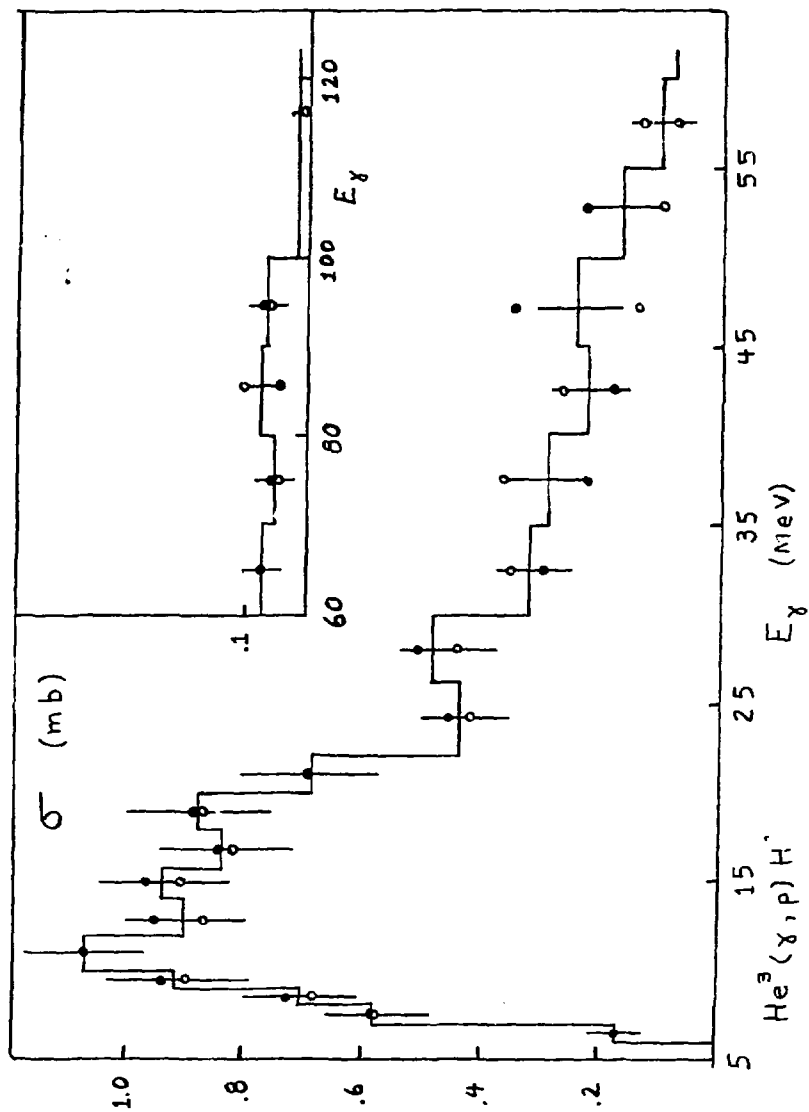


FIG. 11

Таблица 2

Угловые распределения протонов в реакции $He^3(\gamma, p)H^3$

E_{γ} , МэВ	θ	$P(\theta) > \frac{1}{2}$	Δ , лаборатор./ центр	β	γ	δ	ϵ
6-9	13,56	0,131	$56,3 \pm 4,0$	$0,32 \pm 0,10$	$-0,15 \pm 0,19$	—	—
	13,33	0,101	$56,0 \pm 4,1$	$0,32 \pm 0,10$	$-0,21 \pm 0,24$	—	$0,01 \pm 0,03$
	13,28	0,086	$56,1 \pm 4,1$	$0,34 \pm 0,12$	$-0,22 \pm 0,24$	$0,00 \pm 0,02$	$0,01 \pm 0,03$
9-12	7,21	0,615	$118,4 \pm 7,0$	$0,46 \pm 0,09$	$0,06 \pm 0,17$	—	—
	7,19	0,516	$118,2 \pm 7,1$	$0,46 \pm 0,09$	$0,06 \pm 0,21$	—	$0,00 \pm 0,02$
	7,19	0,409	$118,2 \pm 7,2$	$0,46 \pm 0,11$	$0,06 \pm 0,11$	$0,00 \pm 0,02$	$0,00 \pm 0,03$
12-16	5,69	0,770	$102,2 \pm 6,6$	$0,59 \pm 0,10$	$0,18 \pm 0,19$	—	—
	4,34	0,825	$100,8 \pm 6,7$	$0,60 \pm 0,10$	$0,02 \pm 0,23$	—	$0,03 \pm 0,03$
	4,34	0,743	$100,5 \pm 6,8$	$0,58 \pm 0,12$	$0,01 \pm 0,23$	$0,00 \pm 0,03$	$0,03 \pm 0,03$
16-22	8,27	0,507	$70,1 \pm 5,4$	$0,73 \pm 0,13$	$0,70 \pm 0,27$	—	—
	6,86	0,552	$68,2 \pm 5,6$	$0,75 \pm 0,14$	$0,50 \pm 0,31$	—	$0,04 \pm 0,04$
	5,81	0,562	$66,8 \pm 5,8$	$0,65 \pm 0,17$	$0,48 \pm 0,32$	$0,04 \pm 0,04$	$0,07 \pm 0,05$
22-30	7,13	0,624	$54,4 \pm 4,9$	$0,66 \pm 0,14$	$0,30 \pm 0,28$	—	—
	11,53	0,174	$52,1 \pm 5,1$	$0,67 \pm 0,15$	$-0,04 \pm 0,35$	—	$0,06 \pm 0,05$
	3,62	0,822	$52,1 \pm 5,1$	$0,79 \pm 0,19$	$-0,08 \pm 0,35$	$-0,04 \pm 0,04$	$0,06 \pm 0,05$
30-40	12,12	0,207	$39,6 \pm 4,5$	$0,67 \pm 0,19$	$0,63 \pm 0,39$	—	—
	11,53	0,174	$38,2 \pm 4,8$	$0,70 \pm 0,20$	$0,40 \pm 0,49$	—	$0,06 \pm 0,08$
	11,10	0,134	$38,4 \pm 4,8$	$0,81 \pm 0,28$	$0,34 \pm 0,50$	$-0,04 \pm 0,07$	$0,06 \pm 0,08$
40-50	8,51	0,484	$26,9 \pm 4,1$	$1,52 \pm 0,36$	$0,91 \pm 0,56$	—	—
	5,53	0,700	$23,1 \pm 4,7$	$1,73 \pm 0,46$	$0,14 \pm 0,75$	—	$0,23 \pm 0,16$
	4,13	0,765	$20,8 \pm 5,1$	$1,15 \pm 0,52$	$0,00 \pm 0,85$	$0,18 \pm 0,18$	$0,36 \pm 0,24$
50-70	9,18	0,421	$10,8 \pm 2,3$	$1,75 \pm 0,54$	$2,17 \pm 1,10$	—	—
	9,18	0,327	$10,8 \pm 2,6$	$1,74 \pm 0,57$	$2,20 \pm 1,28$	—	$-0,01 \pm 0,19$
	7,11	0,359	$8,8 \pm 3,2$	$1,41 \pm 0,72$	$2,13 \pm 1,58$	$0,30 \pm 0,32$	$0,22 \pm 0,36$

тор \vec{H} , сводится к оператору \vec{z} — компоненты дипольного момента ядра

FIG. 12

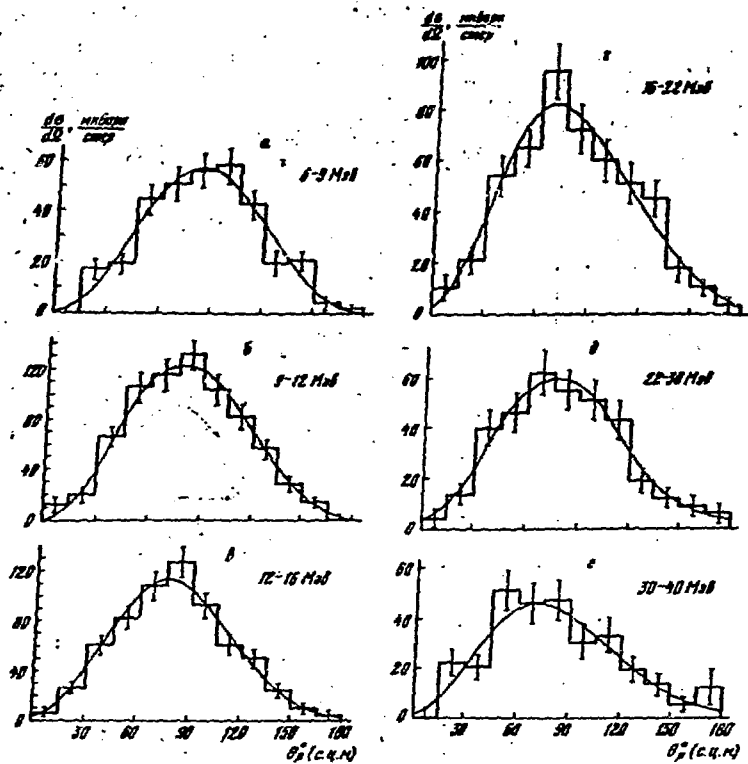


FIG. 13

УГЛОВЫЙ КОЭФФИЦИЕНТ НА ИЗОТОПАХ ГЛИЯ

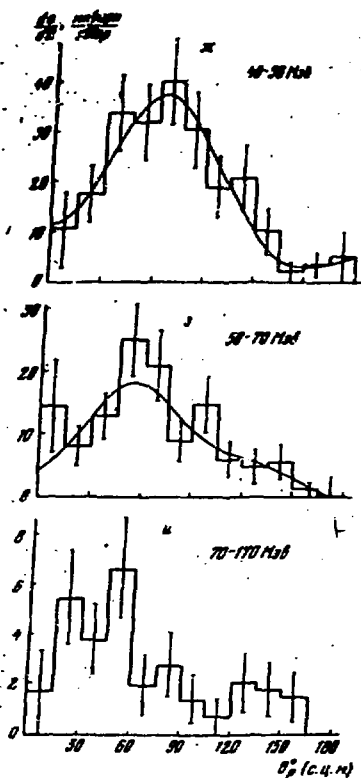
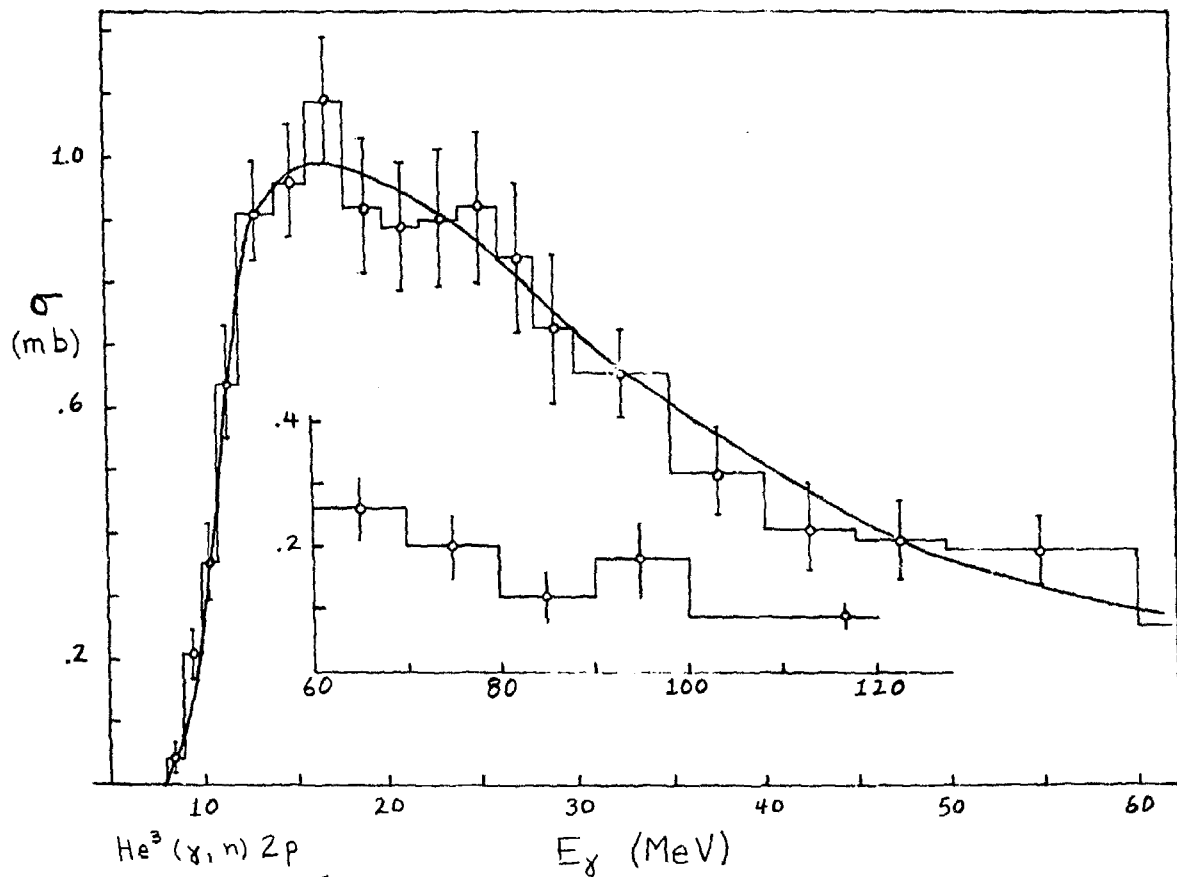


Рис. 6. Угловое распределение протонов в реакции $\text{He}^3(\gamma, p)\text{H}^3$ (в системе центра масс)

По оси ординат отложены дифференциальные сечения, усредненные по интервалам энергий фотонов, указанным на графиках

FIG. 14



$\text{He}^3(\gamma, n)2p$
FIG. 15

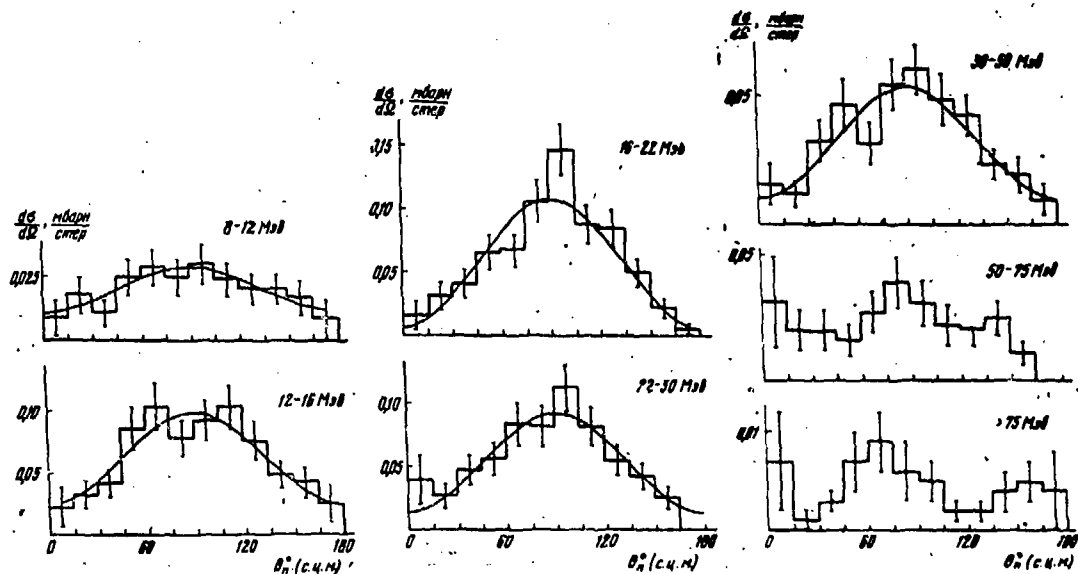


Рис. 17. Угловые распределения нейтронов, испускаемых при реакции $\text{He}^3(\gamma, n)^3\text{He}$ в системе центра масс.
По оси ординат отложены дифференциальные сечения, умноженные по интервалам энергии, указанным на графиках

FIG. 16

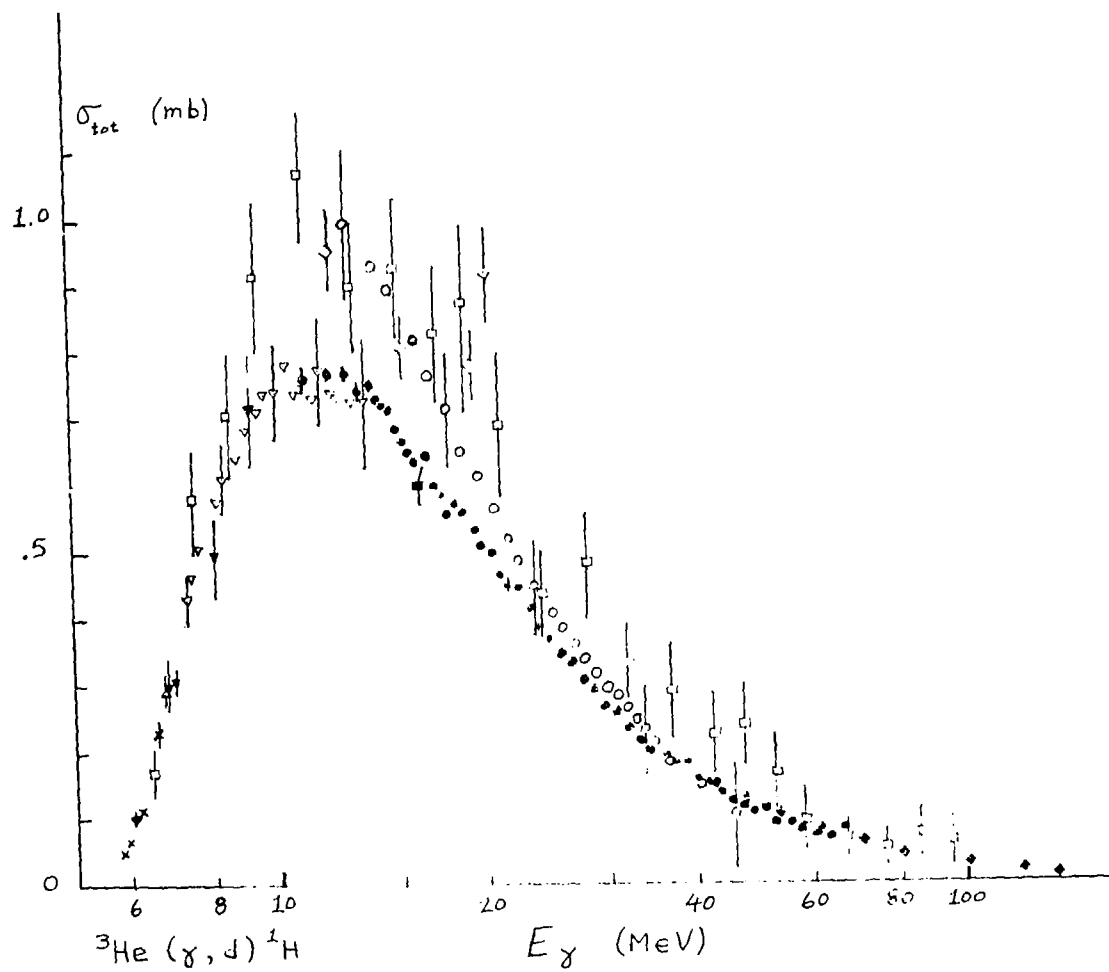


FIG. 17

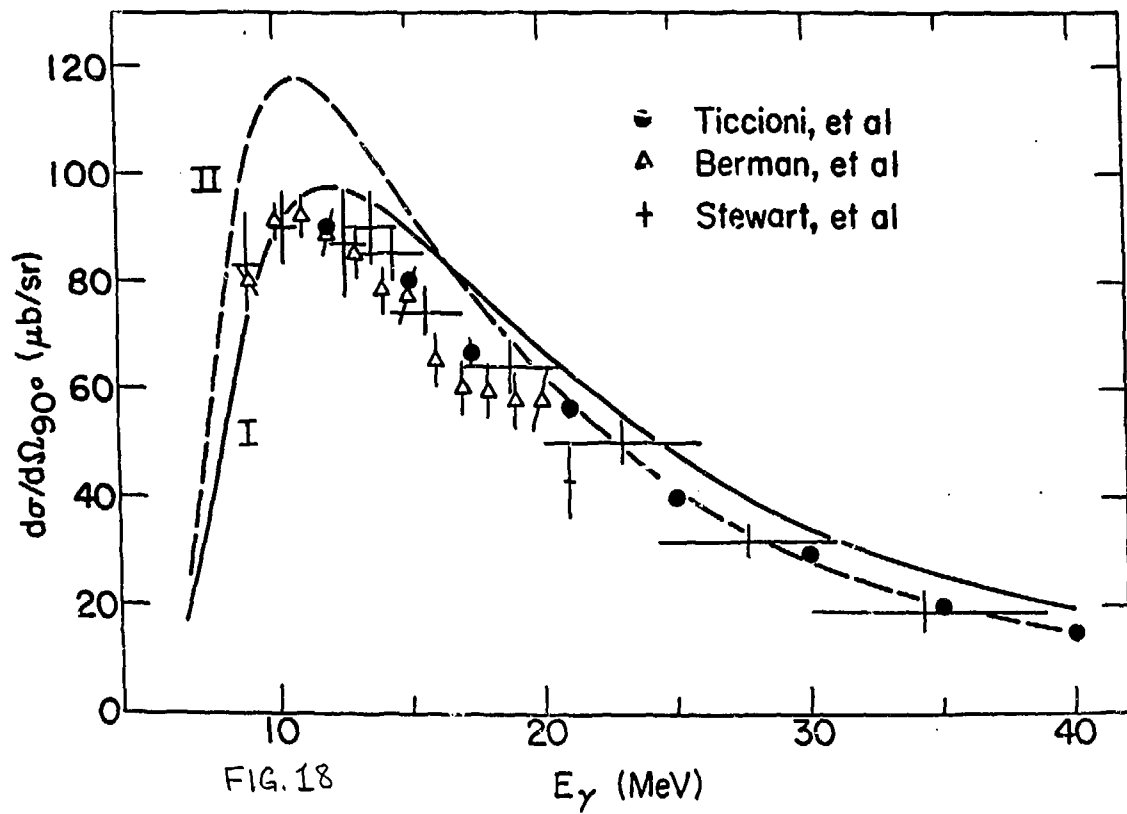
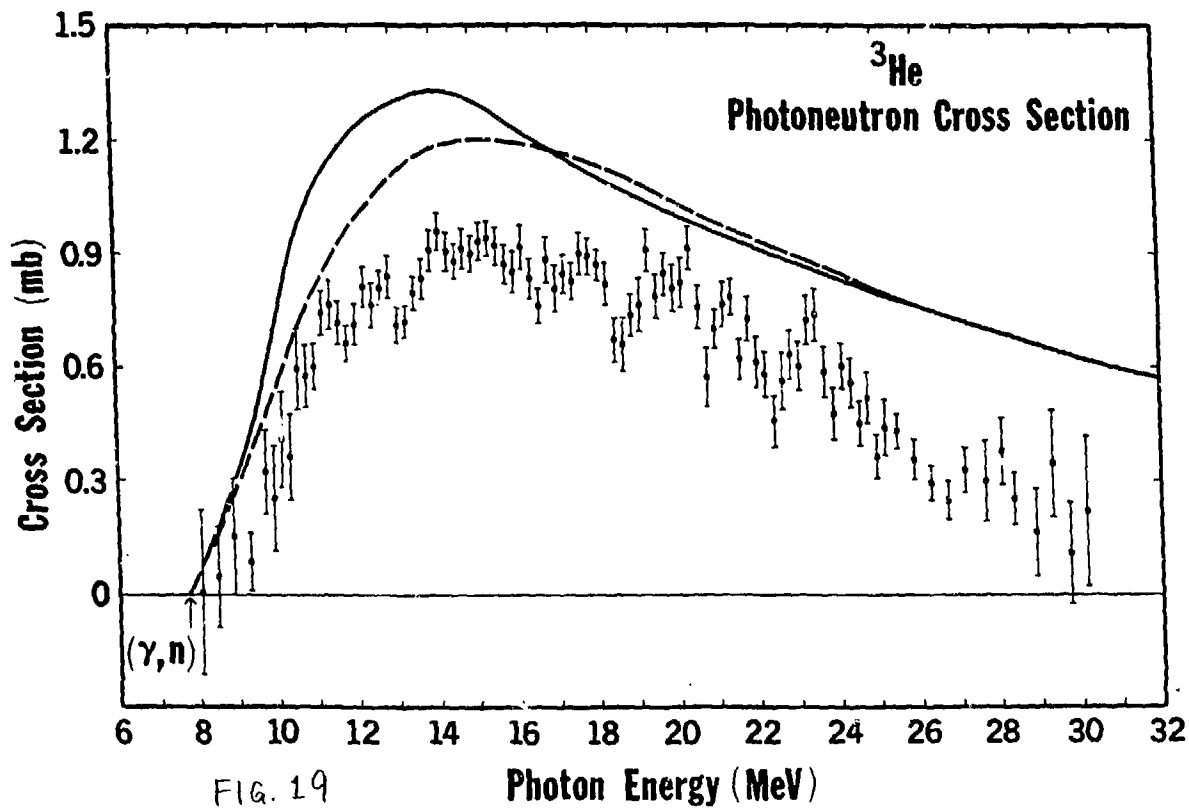


FIG. 18



$^3\text{He}(r, n)2p$

— Gibson - Lehman } Symmetric S-state
 - - - Berbour - Phillips model } ^3He component only

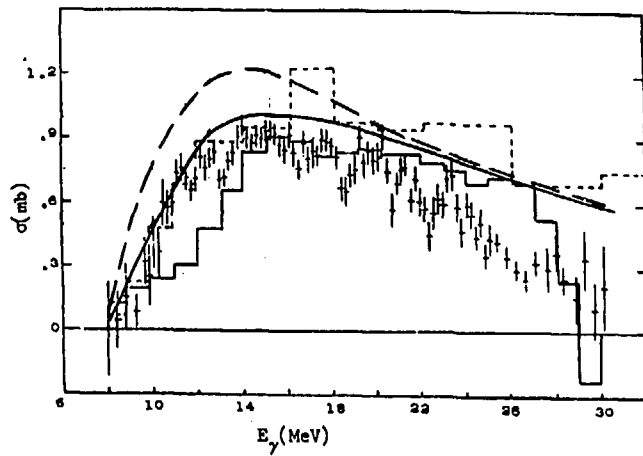


FIG. 20

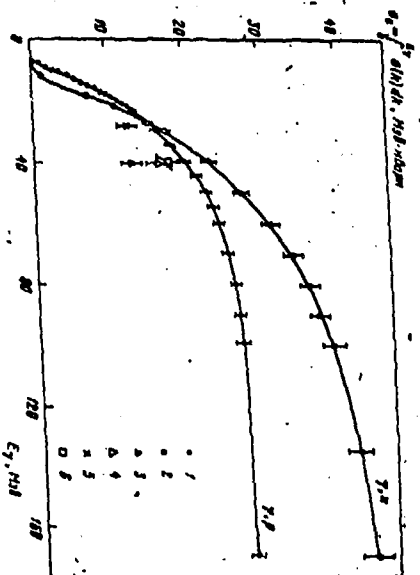


Рис. 16. Зависимость сечения реакции $\text{He}^4(\gamma, p)\text{He}^3$ от сечения реакции $\text{He}^4(\gamma, n)\text{He}^4$ от энергии падающего излучения E_γ .
1 — (γ, p), 2 — (γ, n) — сечения реакций; 3 — (γ, p) (30); 4 — (γ, p) (30); 5 — (γ, n) (30); 6 — (γ, n) (30).

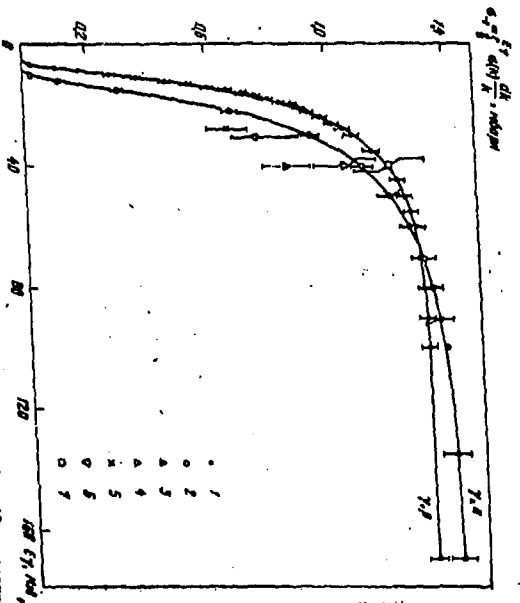


Рис. 16. Зависимость сечения реакции $\text{He}^4(\gamma, p)\text{He}^3$ от сечения реакции $\text{He}^4(\gamma, n)\text{He}^4$ от энергии падающего излучения E_γ .
1 — (γ, p), 2 — (γ, n) — сечения реакций; 3 — (γ, p) (30); 4 — (γ, p) (30); 5 — (γ, n) (30); 6 — (γ, n) (30); 7 — (γ, n) (30).

Fig. 21

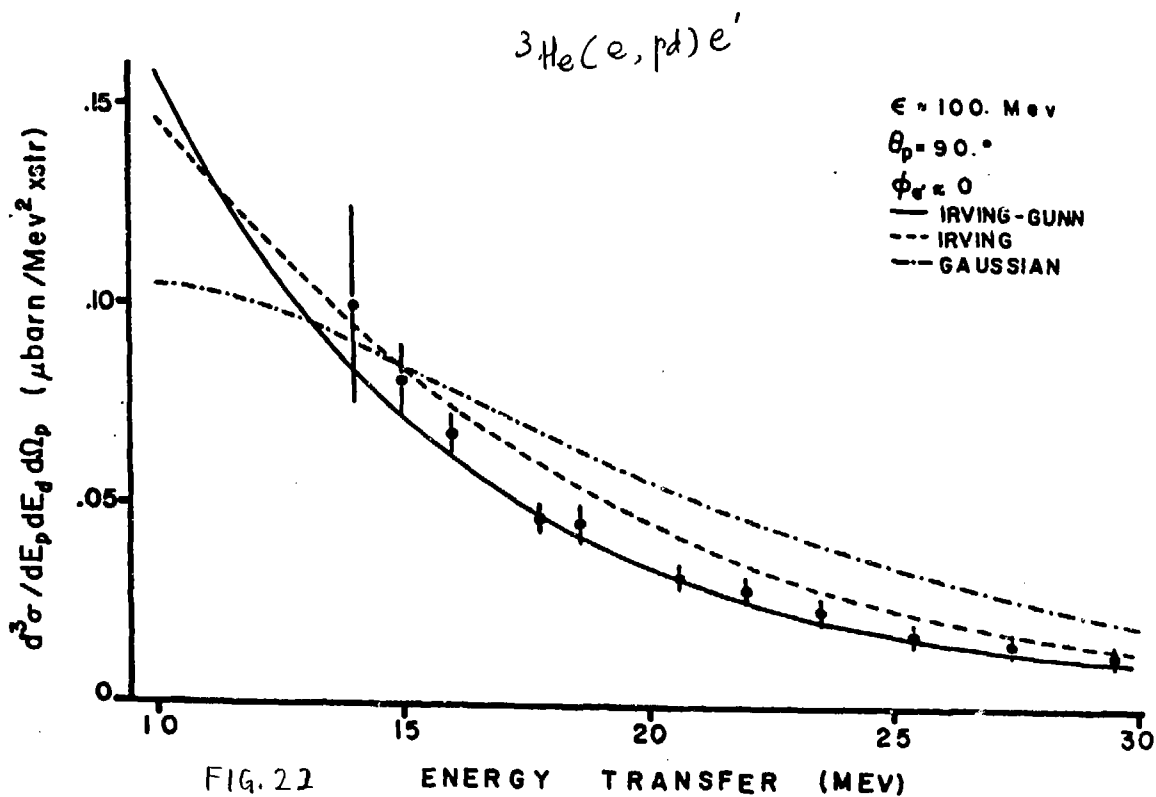
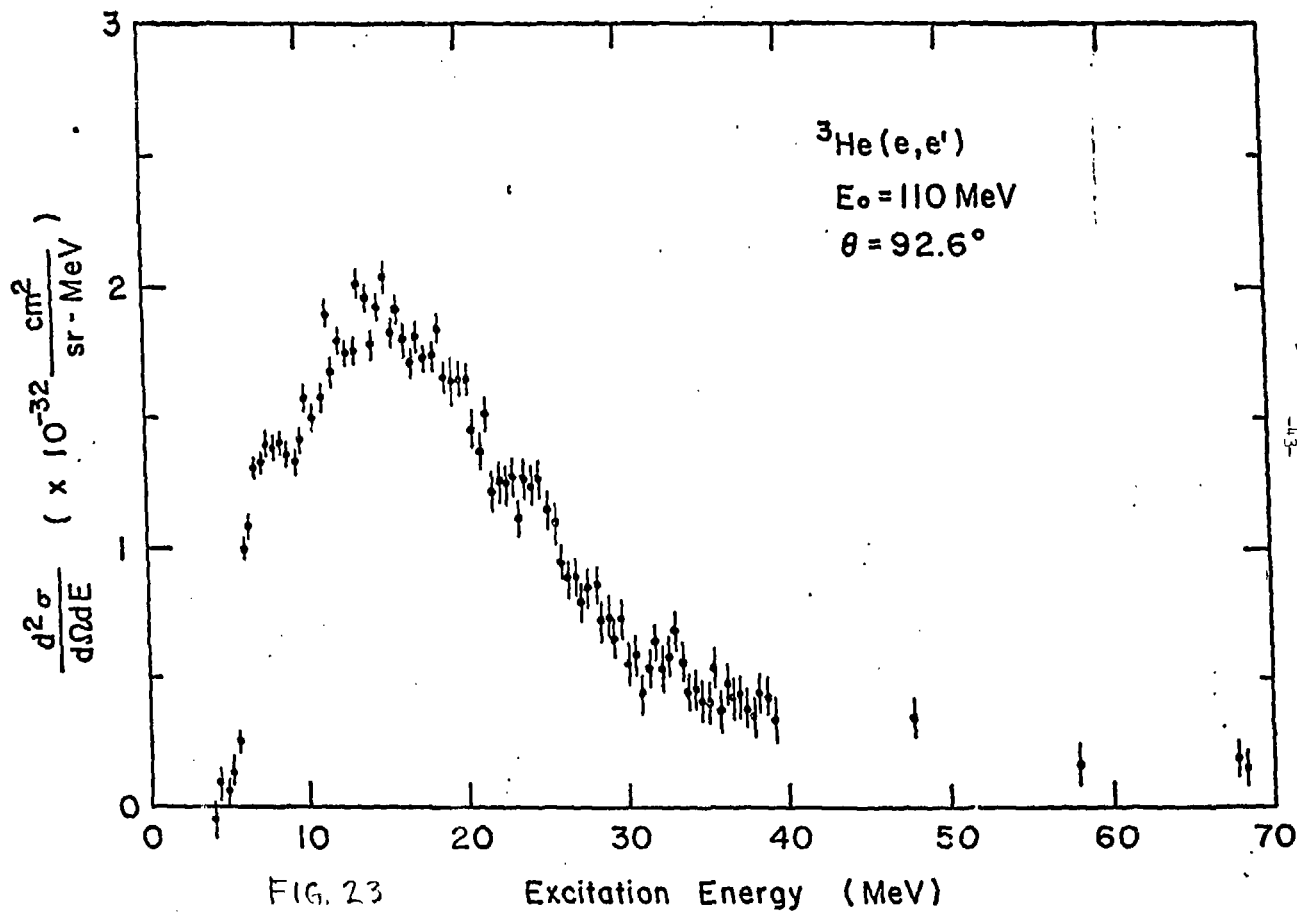


FIG. 22



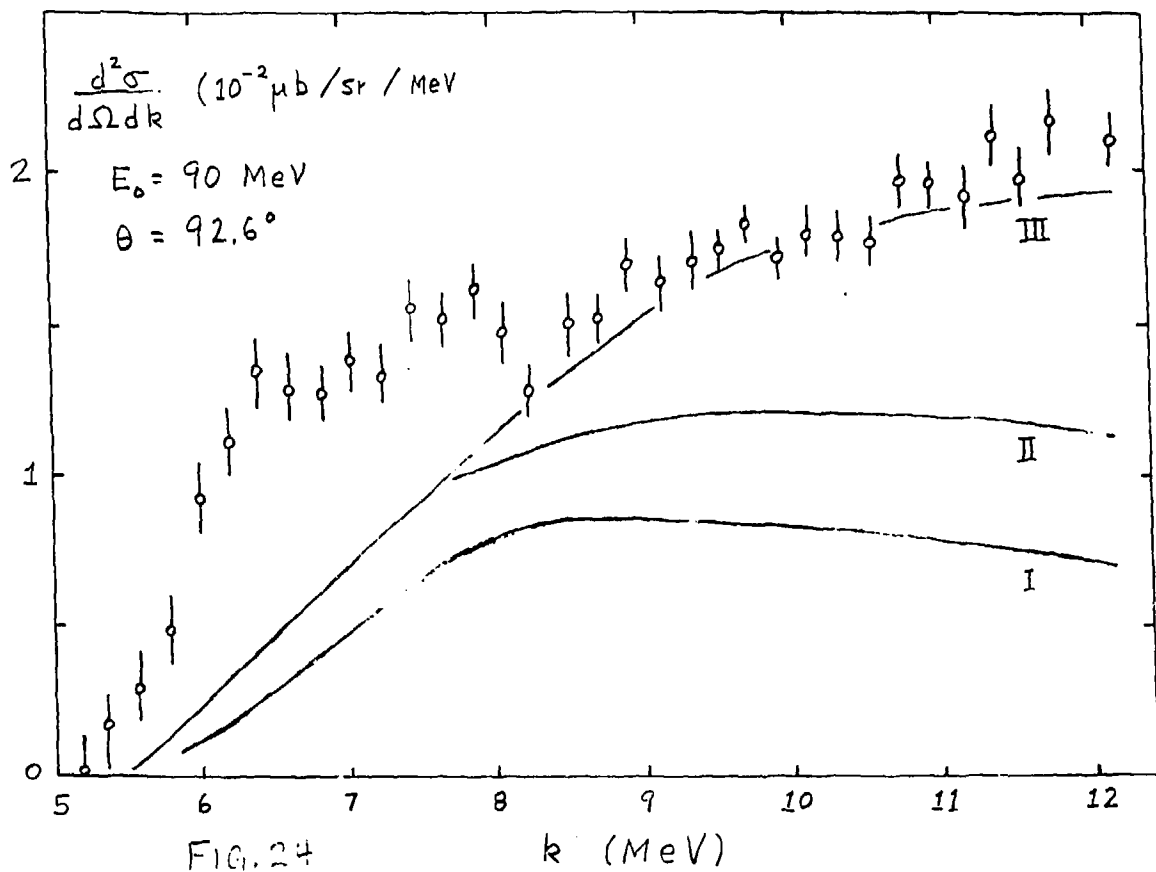


FIG. 24

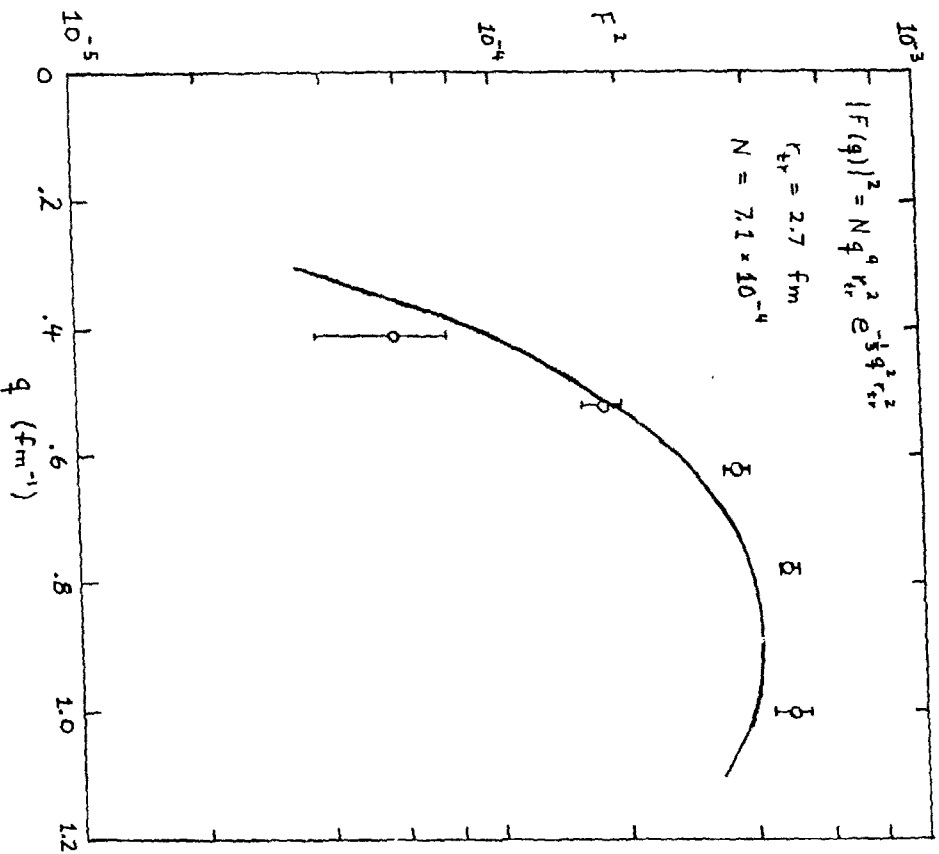


Fig. 25

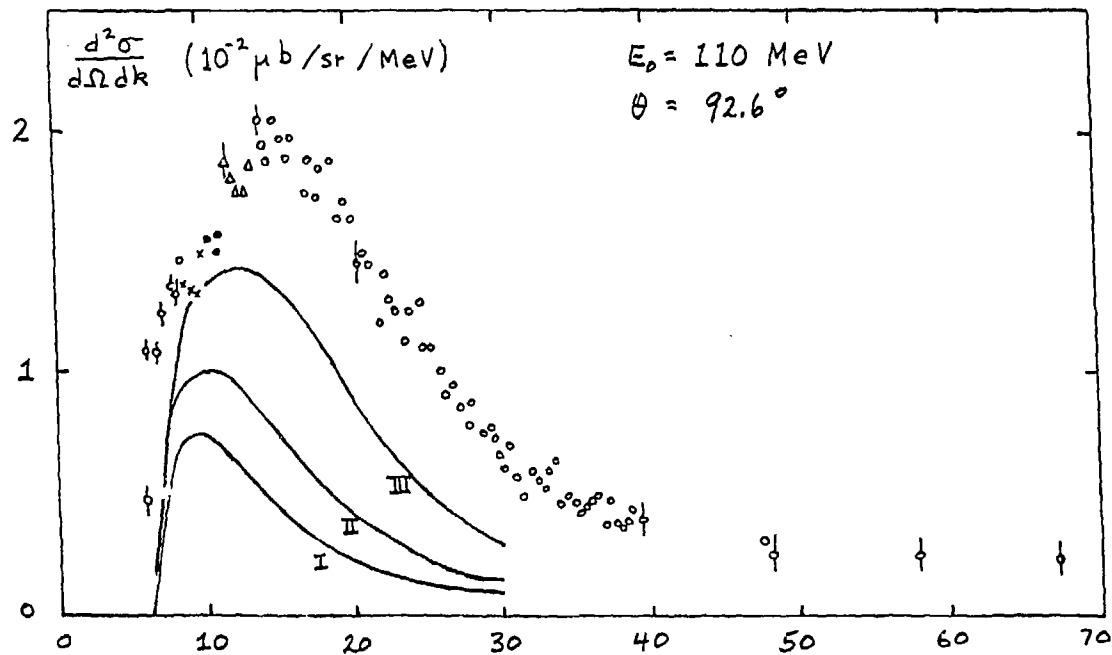
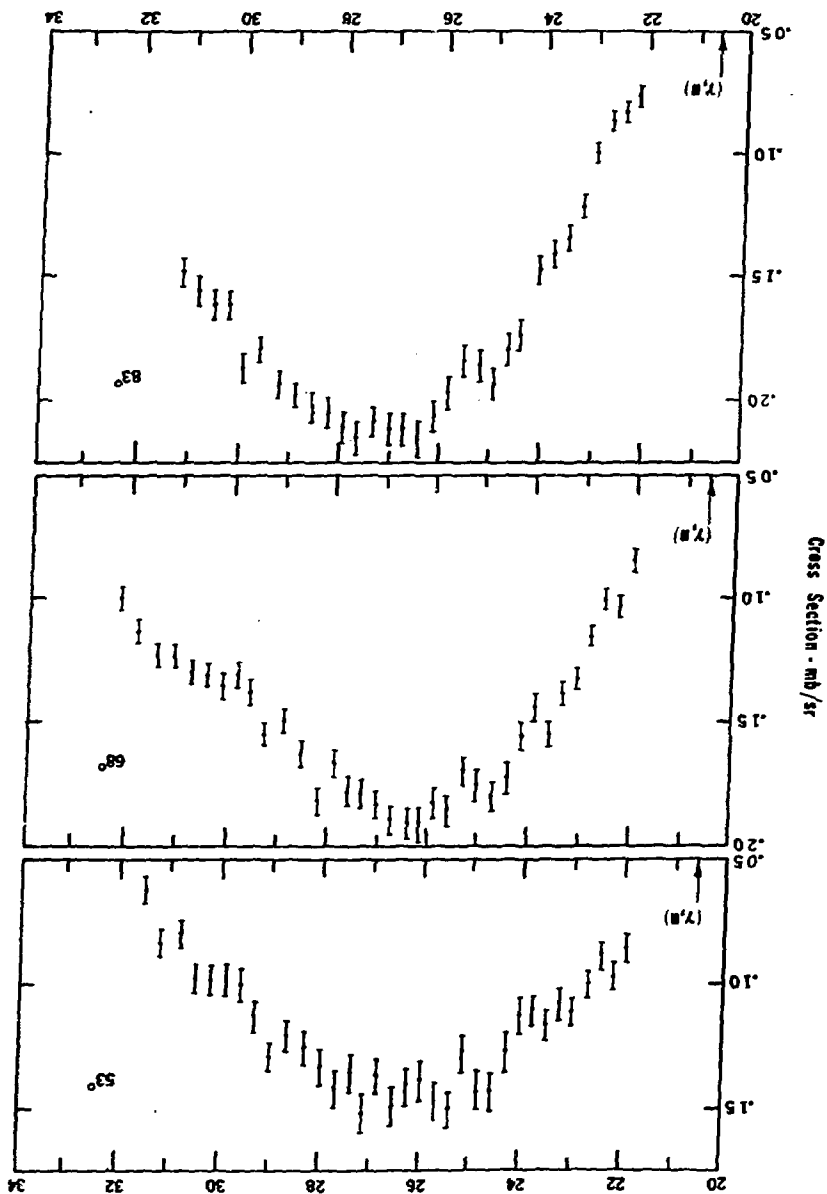


FIG.26 Excitation Energy (MeV)

Photon Energy - MeV

Fig. 27



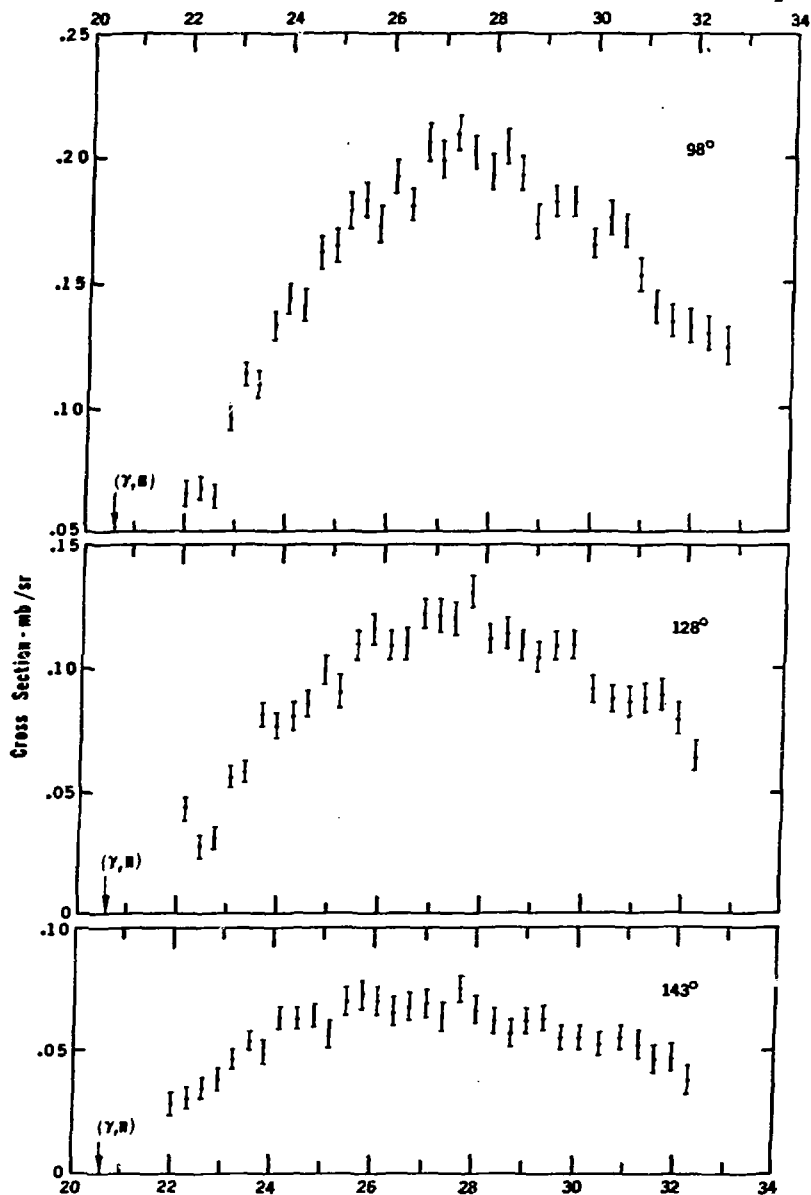


FIG. 28

Photon Energy - MeV

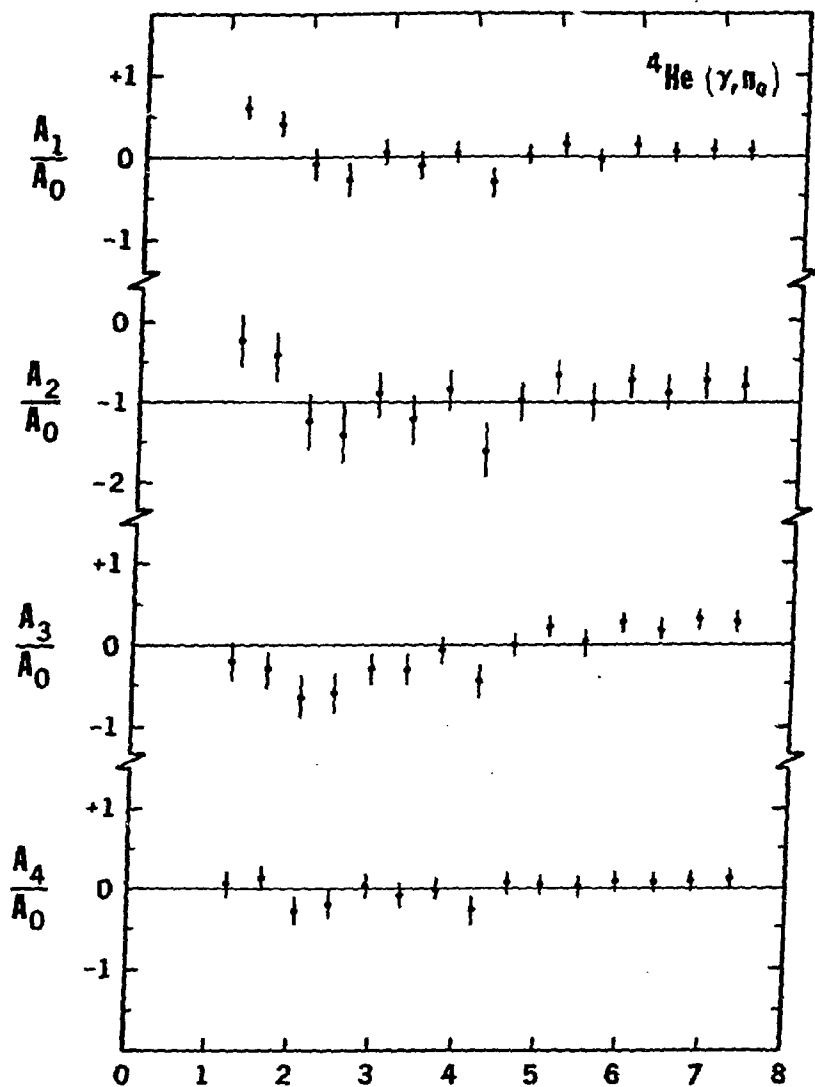


FIG. 29 Neutron Energy - MeV

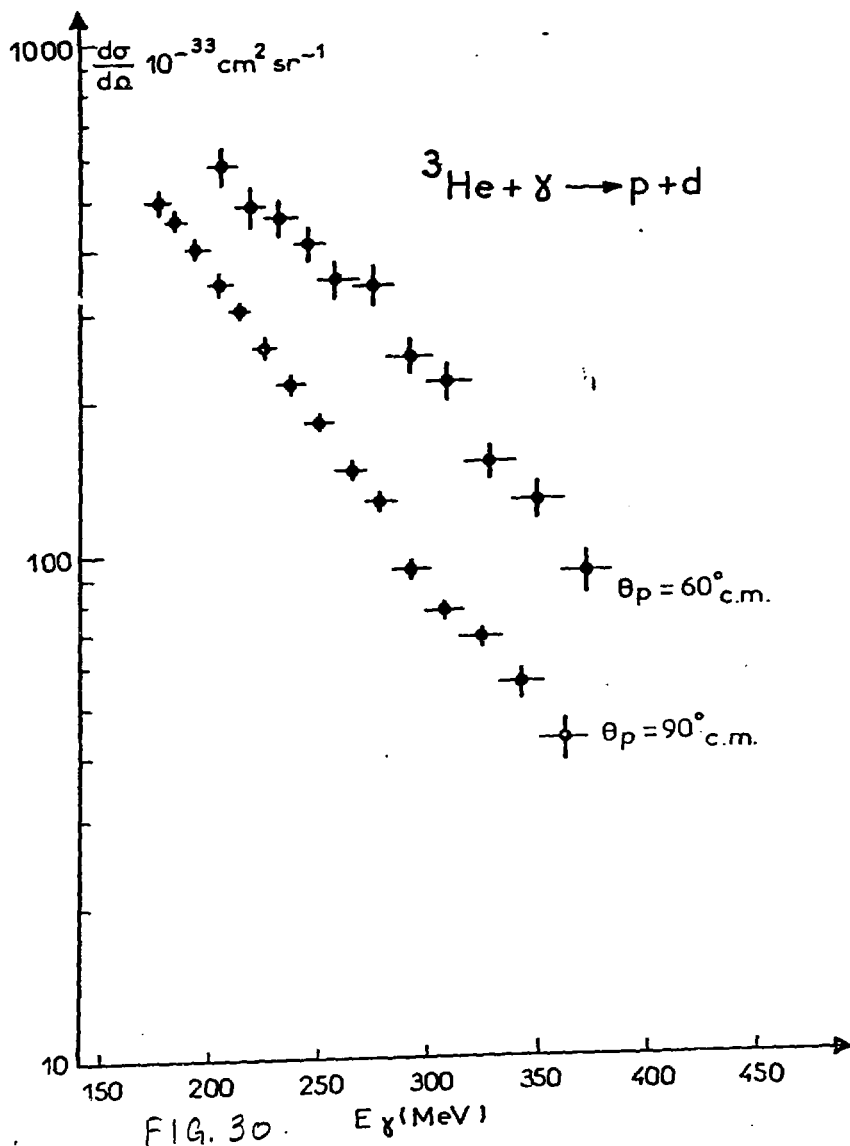


FIG. 30.

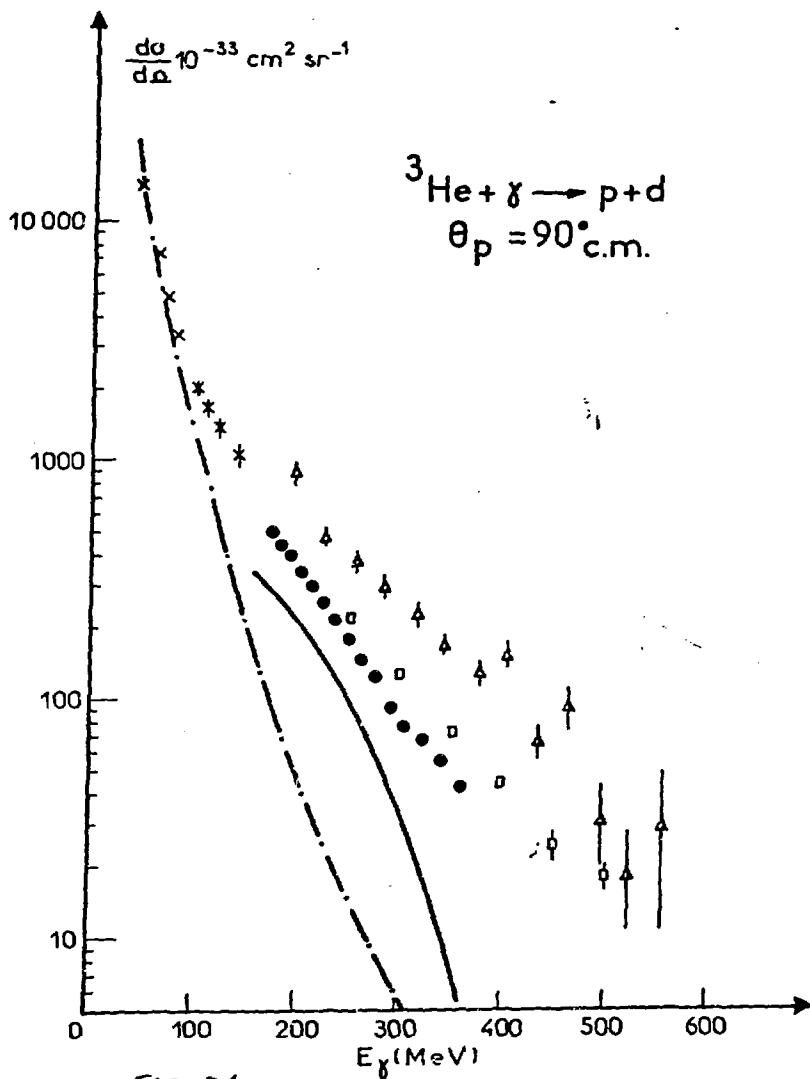


FIG. 31

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● N. M. O'FALLON

◻ C. A. HEUSCH

J. FINJORD: IRVING (w.f.)

— MESIC CONTRIBUTION

--- Electromagnetic (E.F.)

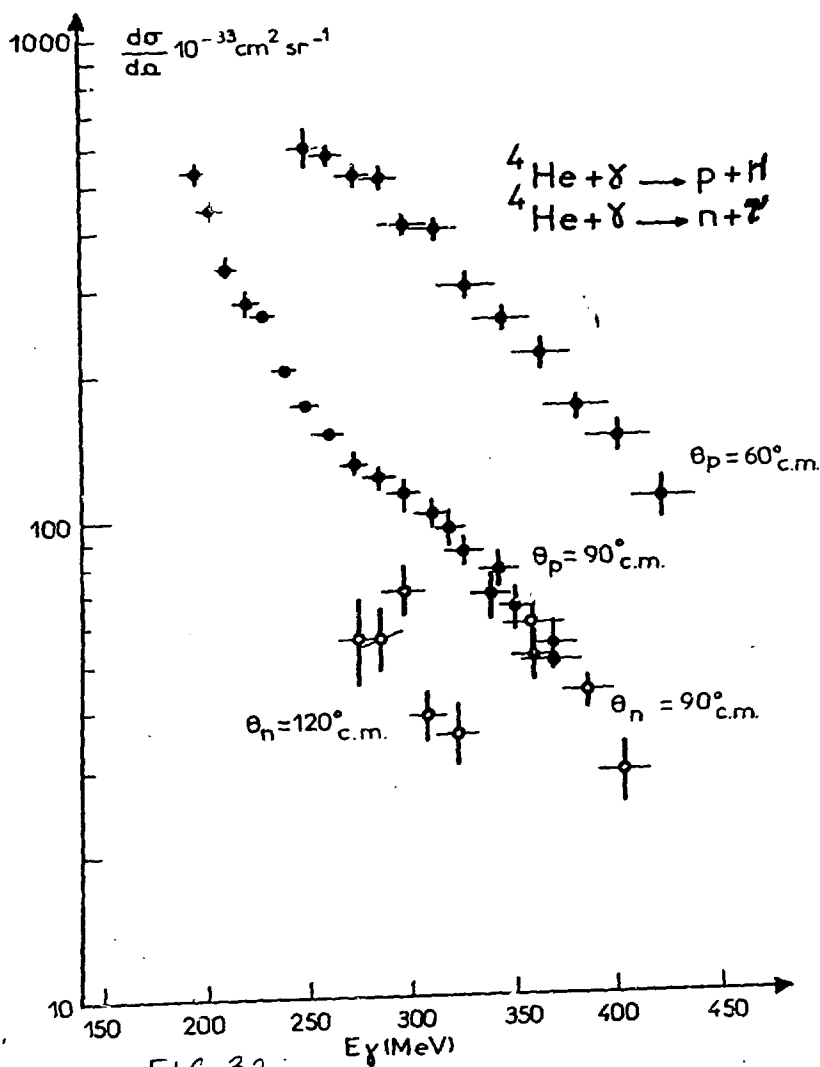
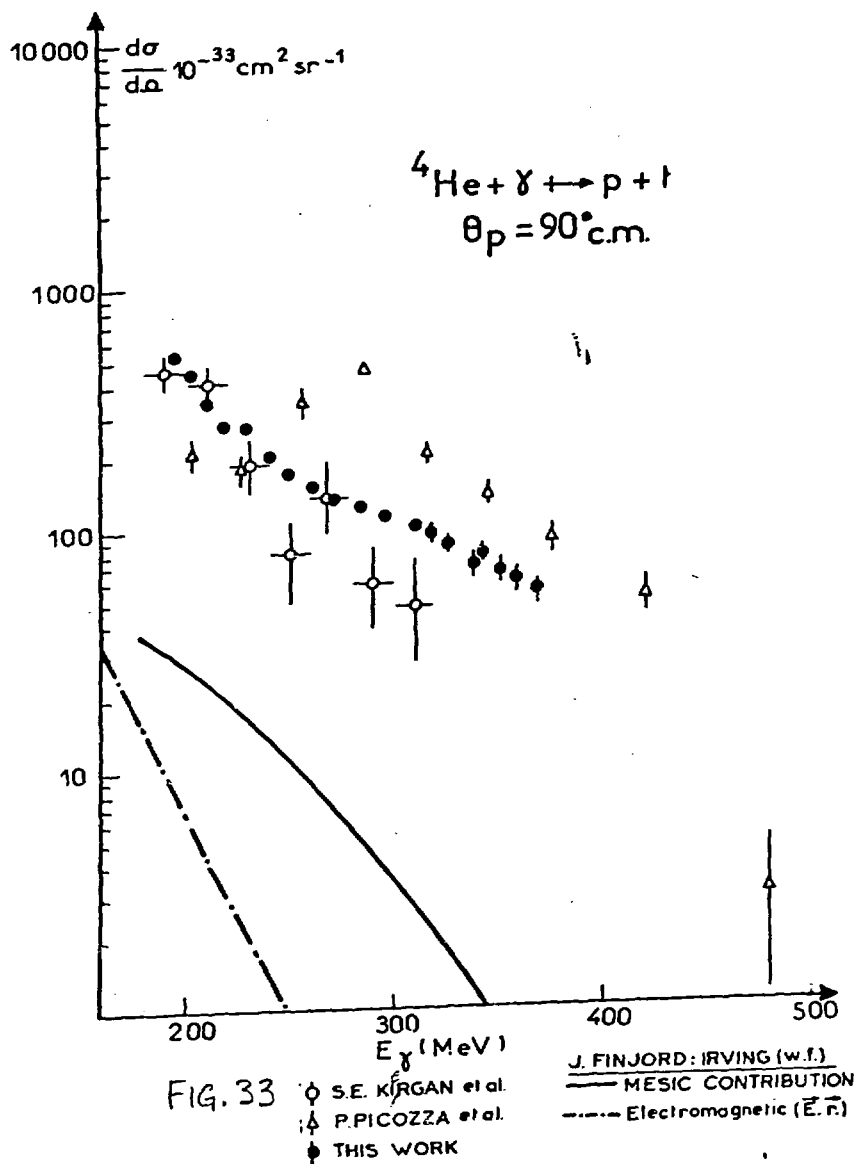


FIG. 32



M. S. Weiss	25
T.I.U.	15
T-Division	3
T.I.C.	27

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